DECLARATION

I hereby declare that this thesis entitled “Assessment of Problems in Prefabricated Concrete elements used in Addis Ababa building projects. The case of building Technology and Construction Sector, ECWC.” is my own original work that has not been presented and will not be presented by me to any other University for similar or any other degree award.

Gebeyaw Taddele ________ _______

Signature Date

APPROVAL PAGE

This MSc thesis entitled with “Assessment of Problems in Prefabricated Concrete elements used in Addis Ababa building projects. The case of building Technology and Construction Sector, ECWC.” has been approved by the following examiners in partial fulfillment of the requirements for the degree of Master of Science in Construction Technology and Management.

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Abstract

Precast concrete is a construction product produced by casting concrete in a reusable mold which is then cured in a controlled environment, transported to the construction site and lifted into place. The basic means of such technique is the use and application of the readymade and standardized building components such as prefabricated concrete elements, modular steel components and prefabricated wood. But, the most important prefabricated building components are that the prefabricated concrete component which is widely used in the development of buildings, roads, railways ,bridges, underground tunnels, pipes and lighting poles.

Because of its greater importance compared to that of cast-in-situ construction methods, prefabricated concrete elements must be understood in detail with its insignificant problems in the use of the construction industries in order to achieve the goals of a country. Hence, the basic objective of the study is the assessment and identification of problems of precast concrete components, especially in building projects. By identifying such problems, the study should provide a clear picture of the problems of PC components in the construction industry and it can fill the gap of using such components compared to that of conventional methods of construction.

The study focuses on the assessment of problems, transportation & storage related factors of these elements in the construction of building projects. Generally, desk study, questionnaire survey and measurements were conducted and analyzed in eighteen sample projects for a total of 42 respondents. According to the findings of this study initial investment cost, transportation and storage cost, the requirement of heavy machines and skilled manpower are some of the major problems in the construction of prefabricated building projects.

Finally, the study indicates that the transportation and storage cost are also the major challenges of the company and it recommends that governmental support for the development of factory is a viable solution to ensure initial investment cost, initiating foreign investors' and the requirement of optimization models for cost planning in transportation and storage costs are some viable solutions.

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Gebeyaw Taddele

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ABBREVIATIONS & ACRONYMS

AA – Addis Ababa.

AAMZLA-Addis Ababa Melese Zenawi Leader Ship Academy

ACI- American Code Institute.

BTCS-Building Technology &Construction Sector.

BS- British Standard.

BCA-Building and Construction Authority.

CBS-Conventional Building Systems.

CPPCC-Code of Practice for Precast Concrete Construction

ERCA-Ethiopian Revenue and Custom Authority.

ECWC-Ethiopian Construction Works Corporation.

GAMS-General Algebra Modeling System.

ICTIC-Information and communication Technology incubation center

IBS-Industrialized Building Systems.

IS- Indian Standard.

JIT- Just In Time.

KMUAO-Kotebe Metropolitan University Administration Office.

PC-Prefabricated Component

PBPPE-Prefabricated Building Parts Production Enterprise
RII-Relative Importance Index

ROI – Return on Investment.

NZ- Newzland.

UAE- United Arab Emirates.

UK-UnitedKingdom.

CHAPTER ONE: INTRODUCTION

1.1 Background

The construction industry in Ethiopia is increasing from time to time in an alarming rate. It can be the dynamic means of production of many infrastructures, which plays a greater role in the economic development of a country. Generally, the construction industry, particularly the construction of buildings require an adequate sources of materials that could provide to achieve the goals of projects which indirectly enhances the productivity of many construction Companies.

The major interest of the study is that population in Ethiopia is high, particularly in urban areas and the need for dwelling is correspondingly high, which is a major constraint for the government to address to each people. On the other hand, conventional method of construction takes a lot of time for completion of projects, it takes a minimum of two years to complete a project. Thus, readymade materials and modular or industrialized method of construction should be the vital alternatives for such problems in the country.

Today the requirement of time, quality and cost are the paramount in the early completion and effective cost & quality management of construction projects all over the world. Residential buildings, public buildings and other high rise commercial buildings would be completed within the intended time to alleviate the needs of people in the country with the required quality. Moreover, the quick & easily assembled ways of different materials should be available for the immediate use & early completion of such projects.

One of the readily made available materials that are very important for building construction is the prefabricated concrete, which is also known as precast concrete. Precast concrete is a construction product produced by casting concrete in a reusable mold or form which is then cured in a controlled environment, transported to the construction site and lifted into place. In contrast, standard concrete is poured into site-specific forms and cured on site. Precast concrete construction methods have now become a feasible and prioritized alternative in the construction and development of buildings, roads and bridges. The primary benefit of prefabricated construction is the speed of construction and minimization of cost. Prefabricated elements can be cast in controlled conditions in a standardized form which is far from the site when they will be needed, stockpiled, and transported to the construction site. The structure can then simply be assembled like a puzzle using the prefabricated components with the help of highly specialized manpower and heavy equipment.

Allowing time for the concrete elements to cure before construction progresses, which is a critical operation in terms of operational time and long-term performance, particularly for a conventional methods of construction, is no longer a factor. The use of precast elements eliminate the operational step, optimize the curing time and cost of construction.

The concept of prefabricated construction includes those buildings where the majority of structural components are standardized and produced in plants in a location away from the building, and then transported to the site for assembly. These components are manufactured by industrial methods based on mass production in order to build a large number of buildings in a short time with a minimum cost. The main features of this construction process in building projects are: The division and specialization of the human workforce, the use of tools, machinery, and other equipment, usually automated, in the production of standard, interchangeable parts and products.

This type of construction requires a restructuring of the entire conventional construction process to enable interaction between the design phase and production planning in order to improve and speed up the construction. One of the key premises for achieving that objective is to design buildings with a regular configuration in plan and elevation. Urban residential buildings of this type are usually five to ten stories high. In general, precast building systems are more economical and save time when compared to conventional multifamily residential construction or apartment buildings in many countries, except some constraints and problems to implement the prefabricated components in building projects, especially in the local context.

Different researchers reviewed about the benefits and problems of prefabricated building components, particularly the concrete prefabricated elements used in the construction of high rise building projects and analyzed in detail the competiveness of the cost, time and quality perspectives compared to that of the cast in situ method of construction. Most of these studies have had providing a greater role in the success and applicability of prefabricated concrete elements in different construction industry, especially in the construction of buildings and roads in the developed countries such as in Canada, UK, China, USA and other European and Asian countries. The prefabricated concrete components observed in the rail road construction of Ethiopia by the Chinese are a peculiar example of the benefits of such elements in time and cost intensiveness. However, prefabrication of concrete parts in the construction industry of Ethiopia is still in an infant stage and never started in construction of projects.

This is because of the reason that knowledge gap and awareness of prefabrication as compared to conventional method of construction and lack of different studies in the local context about the vital benefits and problems of prefabricated concrete building components and the conventional concrete construction and their cost, time, quality &labor intensiveness in the construction industry.

In contrast, the prefabrication concrete parts face different problems in the use of high rise building projects. Some of the major problems and constraints in construction projects are higher initial investment, the requirement of heavy machines and equipment, difficulties of handling techniques, difficulties in transportation and on-site integration techniques, the requirements of trained and skilled manpower in the erection and installation of precast elements. But, the impacts and severity of the problems of the elements in construction projects were not yet observed in detail in previous studies. Generally, this study will be conducted to provide a clear picture of the critical problems of prefabricated concrete components in building projects.

1.2 Ethiopian Building Technology and Construction Sector

The first precast production and construction company in Ethiopia is Prefabricated Building Parts Production Enterprise (PBPPE), which was established in 1987 GC with the help of the socialist country of Yugoslavia. The company was named Prefabricated Building Parts Production Enterprise (PBPPE) until September 2016 GC. The basic aim of the establishment of the company was to reduce the wastage of natural resource like formwork reduction and to alleviate the immediate requirement of housing and now they are termed as low cost house due to the least construction cost and short period construction.

But, after this time it is reorganized and reformed under the Ethiopian Construction Works Corporation (ECWC) and is named as the Building Technology and Construction Sector (BTCS) and it is also a grade one contractor.

Back then, the country was at an infant stage in construction, with only a number of modern buildings constructed in Addis Ababa, mainly with no prefabricated elements. Within its 30 years of operation, EBTCS has not yet shown much progress as an organization; still it uses the same outdated batching plant, crane system, and even molds that had been installed during its establishment throughout the previous years and it has fixed specifications for every single component of building construction. The dimensions are still specific and limited that do not use for very longer dimensions. However, BTCS mainly focused on the production of components and construction of such components. It is not limited in the production and installation of the elements of precast concrete, the company also engaged in the construction of conventional or cast-in –situ methods of construction as a contractor in Ethiopia. Hence, its basic operations are the production of components of the building, constructing (assembling) the building with the components on site and it also involved in the construction of cast-in-situ methods of construction. These prefabricated components that are produced in the BTCS are reinforced slabs, panels, walls, stairs, columns, partition walls and beams.

Generally, the prefabricated methods of construction are either the composite or full prefabricated methods of construction. Composite methods are those construction methods that are the use of techniques of both the prefabricated elements and cast- in-situ methods of construction on the same building. BTCS consists of different departments such as the construction department, production department, logistics department, estimation department and sales department (Kibirt, 2017). Every department has its own civil engineering professionals that are involved in the design, construction, estimation and supervision roles either in head office or on their construction Sites.

Currently, BTCS construct three-governmental prefabricated buildings in Addis Ababa through assembling of components, such as Information and communication Technology incubation center (ICTIC) around Gorro, Addis Ababa Melese Zenawi Leader Ship Academy (AAMZLA), which is located around Ayat and Kotebe Metropolitan University Administration Office (KMUAO).The company also constructs the head office of governmental organizations in Addis Ababa by composite methods of construction. Some of them are Ethiopian Revenue and Custom Authority (ERCA) and Ethiopian Science and Technology Minister (ESTM) etc.

1.2.1Components of prefabricated concrete

In precast construction, there are common elements that should be produced in the factory like; slabs and cantilevers, girder beams, shear walls, columns, footings, landing, stairs and beams. Here, shear walls are rarely produced in the factory while the rest of the components are a common type of elements produced in the company. The elements aforementioned above are produced in a specialized molds and each of the components are also prefabricated with a fixed standards.

1.2.1.1 Slabs and cantilevers

The most common slabs prefabricated in the factory are a square type which is standardized as 4.2*4.2 m^2. According to the company's history, it is mentioned that the dimensions of the slab were not limited to 4.2m length and 0.22m thickness. The dimension was varied in size like that of public buildings. This standard of molds was built during the beginning of the development of the company and its size is about 7.2*3.5 meter span for slab. But, today slabs are limited in span because of the existing molds are limited to such dimension in the factory and previous molds of various sizes are out dated in the factory. Molds are the basic constraints for the design and development of different sizes, dimensions and shapes of the elements in the factory. Likewise, cantilevers are produced in a fixed standard mold of dimension 4.2*1.2 m^2. Standard Molds of the elements are required to be one of the critical initial investment cost for production of different dimension of components.

Because of their greater sizes and heavier weights, slabs are the most complicated parts of building components during production, erection and the whole construction processes like that of movement in the factory for curing, handling for transportation and installation stage compared to that of other building components that are produced in the company.

Fig1.1 Slabs and cantilevers stored at Ayat project **Cantilever**

1.2.1.2Columns and Girder Beams

Columns are also a prefabricated elements produced in the factory which requires a specified mold size for production. The common mold size of columns in the factory is 30*30cm^{2}and 34*34cm^2.Here, the elevation of columns should be designed for an individual story, and or it should be designed a single columns to cover the whole story of the building. Moreover, the common height of the columns are 2.68m for a single story, 5.79m for two-story and 8.69m for three-story buildings including the slab size of 22cm^2. During earlier times of its development of production, the company was using a column size of 50*50cm^{2}dimension, particularly for public building of slab up to 7.2 meter span.

Even if, the reformation of the company initiates to promote and accelerate the production and construction of prefabricated concrete construction, still it has limited number of mold dimension for every specific element in the company. Girder Beams are also produced with mold size 0.24*0.24 m^2 and a span of 3m center to center. They are used at the edges of buildings and some beams are used as an intermediate beams in the factory. But, most of the time intermediate beams are no required in the construction of slabs, because of the fact that different slabs are connected and grouted together to form such forms of beam

Columns Girder beams

Fig1.2.Columns and Beams in Goro and Ayat

1.2.1.3 Footings and Pads

Pads and footings are other concrete elements that are produced and transported to the site in the company. Pads are designed and produced with different dimensions depending on the soil capacity of the project with a specified mold. Therefore, the basic dimensions of footings are commonly 1.2*1.2*0.8, or 1.6*1.6*0.8 and or

2*2*0.8(m^3).The depth is the same in whatever is its area. Footings are comparatively less sophisticated during assembling and handling of the components.

1.2.1.4Stairs and Landing

Stairs and landings are common precast elements that are fabricated in Building technology and construction sector in different dimensions as per the company standards. Landings are produced with size 3.90*1.64 and Risers are fabricated with dimension 2.90*1.20 in the company.

1.2.2Mix Design and curing parameters

The common ingriegents of the concrete mixture of that of prefabricated elements produced in BTCS are mostly that of the aggregate with 0.2mm size, Langano sand and an ordinary Portland cement(OPC) like that of Mossebo and Mugger cement. The common mix design in the company is the weight method and is designed for (1/3) m^3 or 0.33$m^3$of concrete. During mixing, 2 liter of Admixture (AD460) is added to accelerate the curing time of the mix for each of the designed mold types.

In this case, the curing period of slabs and cantilevers are reduced to 20 hours and that of columns, shear walls and girder beams are reduced to 24 hours due to the use of these admixture. However, the factory was using steam curing formerly that cures slabs within 8 hours, but now due to the requirement of skilled man power to repair and maintenance cost of molds, it is replaced by admixtures.

Further, the common concrete Grades designed and produced in the factory are C-30 and C-40. C-30 Concrete components are shear walls, footings, stairs and landing whereas C-40 concrete components include that of slabs, columns, girder beam, cantilever etc. The compressive strength test is the main quality control method during production of concrete (C-30 and C-40) in the company.

According to the factory standard, if the 7 day compressive strength attains about 70% of their maximum strength **(**i.e. Minimum 21Mpa for C-30 and 28Mpa for C-40**)**, then the concrete can pass but if the 7 day compressive strength is less than70% of their maximum strength ,then the concrete grade is rejected and tested again.

1.2.3 Installation and Connection parameters

In prefabricated construction unlike to conventional one, the most and reliable importance is that the design consideration of earth quakes and seismic resistance. Therefore, every prefabricated construction is designed to sustain the external loads so that the earth quake and seismic loads are designed to be zero in the overall construction of such method. In this case, the pre stressing wire plays the prominent role in the load transfer parameter of prefabrication construction and the supporting resistance of the elements in building. Hence, these wires are elongated throughout the channels of slabs and holes of girder beams and cantilevers in each floor and finally grouted with concrete forming an intermediate beams.

This way the company does not prefabricate such types of beams for construction. Moreover, the grouted concrete acts as an intermediate beams for precast construction and this form of beam is constructed and grouted between each element during construction and installation phase of elements. Generally speaking, such form of elongation with high tensile wires and grouting of concrete along the span of slabs and beams or cantilevers increase the tensile stress of the overall structure of the building that do not easily disintegrated by other external loads.

In larger context, the installation and construction of precast buildings is simply the role of the longer and thin extension wire between members of the elements that could avoid the existence of external loads. So, the connection is based on the method of friction created at the four corners of the components.

Fig1.3 Installation of cantilevers

1.2.3.1 Pre stressing wire, wedges and barrels

In pre stressing wire, wedges and barrels plays the basic role of elongations of wire during the alignment and connection of the slabs. Wedges and barrels are commonly called males and females in which case wedges are bundles of two pairs of wire passing through the barrel and barrels are those rigid plates that handle the bundles of wire together before grouting of the concrete above the wire forming the beams of the slab. In this case, slabs or cantilevers are supported at the four corners of the columns by producing the friction on it. Moreover, the pre stressing wire, barrels and wedges are the critical materials in the alignment, connection and finally supporting of the elements during the installation and construction of prefabricated components**.**

Wedges

Fig.1.4.prestressing wire, wedge and barrels Pre stressing wire

1.3. Statement of the Problem

Some of the problems that initiate the researcher to conduct this study are the following.

- One of the most facing problems of prefabricated construction in the local context is that of transportation & storage techniques to address into each construction projects. During transportation &handling, especially in long distance, the prefabricated concrete elements should takes time and money and it should be cracked, damaged &leads to wastage.
- The construction of prefabricated concrete components needs a specialized and skilled manpower for the installation and erection processes .Thus, a trained and skilled human labor affects the productivity of prefabricated concrete elements in our country and it may lead to poor quality of the precast construction, especially at the integration and connections for prefabricated concrete parts of high rise building construction. Farther, the requirements of technical and skilled manpower plays a greater role for the construction of prefabricated concrete elements and erection techniques and need to be solved in building projects.
- The initial capital cost of the production and development of prefabricated concrete parts is a chronic problem in the improvement and use of prefabricated concrete elements in building projects of Addis Ababa.
- The importance of heavy machines & equipment are also other major constraints in the installation, handling & assembling of prefabricated concrete elements to use in building projects in the country and such requirements may be other challenges of precast construction which also need for maintenance cost of heavy machines &tools. This problem may lead to on site disintegration of component at the construction projects unless efficient & sufficient equipment are used .
- Most of the clients & contractors are influenced by traditional cultures; they prefer conventional concrete rather than prefabricated concrete. Therefore, the influence of traditional cultures &knowledge gap of using conventional concrete is the major problem in the use of prefabricated concrete components in Ethiopian building projects.

1.4. Significance of the Study

The study of this thesis will provide a clear picture of the awareness of critical problems and constraints of prefabricated concrete components in high rise building projects by assessing the constraints and challenges of prefabricated Concrete elements and it can fill the gap of using these components and it also plays an important role in the success of building industrialization in Ethiopia.

1.5. Research Questions and Objectives of the Study

1.5.1. Research Questions

- Do prefabricated components face problems in construction projects?
- List the major problems of prefabricated concrete building components in the construction of building projects in Addis Ababa?
- Rank the problems of prefabricated concrete elements used in Addis Ababa building projects and determine the possible solutions of these problems.

1.5.2. Objective of the Study

To assess the major problems of prefabricated concrete components in the construction of building projects in Ethiopia.

1.5.3. Specific Objective

- To identify and review the critical problems of prefabricated concrete building components, especially in the construction of building projects in Addis Ababa.
- To initiate cost planning techniques of prefabricated concrete elements in the construction of building projects as well as in production factories.
- To minimize storage, transportation and construction cost of prefabricated concrete building parts in construction projects in Ethiopia.
- To provide an in depth roots of prefabricated concrete components in the use and application of building projects in Ethiopia.

1.6. Scope of the Study

This thesis addresses the general objectives &tries to provide some solutions to the major problems of prefabricated concrete components in the construction projects .It mainly focuses on the problems of prefabricated concrete elements in the construction industries, particularly the assessment of transportation ,handling &installation techniques of these elements in the construction of building projects in general & the awareness and accessibility of the elements to each building projects in particular.

Finally, it will have the relevant information which helps to identify the critical problems of prefabricated concrete elements in the construction of building projects in Addis Ababa.

1.7. Limitation of the study

In the study of the research problems, the most frequent limitations and challenges of the study was lack of adequate research and investigations on the area. And other limitations were also faces that there is only a single prefabrication production company in Ethiopia which is governmental, that may or may not provide enough information for the study and no private production and construction company.

Moreover, the former Enterprise, Prefabricated Building Parts Production Enterprise (PBPPE) constructs only limited number of buildings that are around 105 buildings in Ethiopia which are full prefabrication, installation& erection of these elements to assemble as a single unit. This method of construction is called full prefabrication. The new company, Building technology and Construction Sector (BTCS), is very recent organization and don't have adequate experience in the construction of prefabrication, even if most of the engineers, supervisors and skilled manpower are not changed and currently it only constructs around four projects that was limiting the source of the data.

1.8. Organization of the study

The thesis is structured and organized with five major components. The first chapter describes the basic research backgrounds as an introduction part of the research. The second chapter contains the basic literature review which includes from the ancient origins of prefabricated concrete parts to the current trends emphasizing with their advantages as well as the critical problems in order to make up the conceptual framework of the study. The third part covers the Research design and methodology. Analyses of findings, interpretations and discussion on the basis of results are presented in detail in the fourth part of the study. The last part of the study contains the conclusions and recommendations forwarded to the people. The following diagram shows the flow of chapters that are compiled in the study.

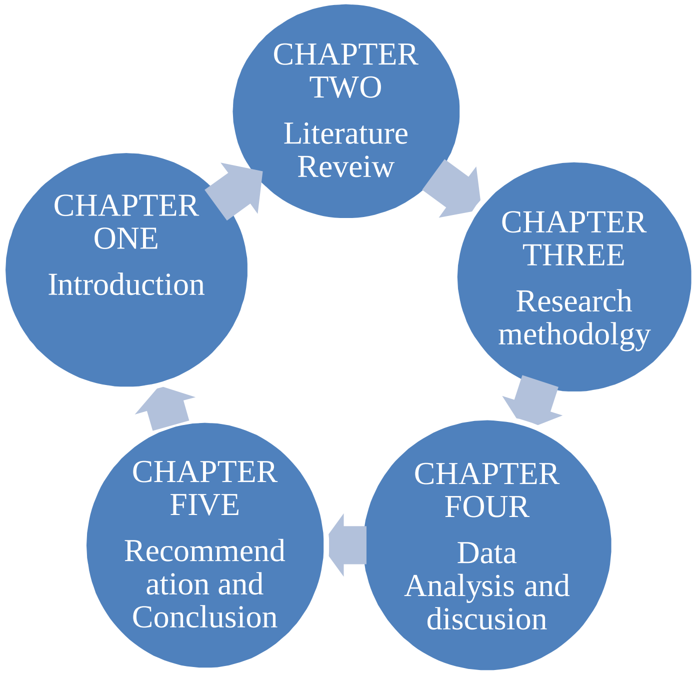

Figure 1.5 Flow Chart of the Research Outline.

Chapter I: Introduction; This part contains discussions on background, significance of the study, statement of the problem, objectives and research questions, scope, limitation and organization of contents of the study.

Chapter II: Literature Review; This part of the thesis discuss on different definitions, origins of prefabricated concrete elements including building construction methods with emphasizing the benefits and major problems of prefabricated concrete parts. This chapter also analyzes in detail the different problem assessment techniques and methods are discussed broadly.

Chapter III: Research Methodology; It covers the research methodology as a single chapter. The methodological approach consists of the overall research strategy, the research areas, research techniques, tools and method of data analysis.

Chapter IV: Discussion, interpretation and Data Analysis; this part of the study also contains results of the assessment problems of prefabricated concrete parts in Addis Ababa building projects. It is divided into different parts containing findings on assessment of problems of prefabricated concrete components and the suggested techniques to solve the problems of precast building elements in construction projects.

Chapter V: Conclusions and Recommendations; at the end based upon the data collected and analyzed during the study period conclusions and recommendations are forwarded.

CHAPTER TWO: LITERATURE REVIEW

2.1. Relevant Definition of Prefabrication

In ancient times, it was the belief of the author of this work that prefabrication existed as a construction method on its own. However, it has been found that the term “Industrial Building System” has several related terms: modularization, prefabrication, preassembly and industrialization. The categorization of these terms will be discussed in detail in the sections below based on a thorough literature review of these terms and their scope of use. For the purpose of this research, prefabrication is considered as the main IBS under study, and the term will be used in reference to modern construction methods.

Several studies indicate that the definition of prefabrication is as widely varied as its terms of reference. Prefabrication could either be classified under IBS or modularization, or defined independently. In order to establish an understanding of the term and its relevance to this research, and allay the erroneous, an appropriate definition will be established based on previous related works. According to (Haas et al. 2000)), the various definitions which exist are subjective to time, industry and the purpose of the study as there is no organization monitoring the progression of these technologies, besides the building technology and construction sector. In addition, several terms are used interchangeably in reference to prefabrication. The usage of these terms is predetermined by the user’s philosophy and understanding and also varies from country to country. The associated terms are defined briefly below, in order to gain an understanding of the fundamentals of prefabrication.

Modularization: Modularization is defined as the off-site construction of a whole system prior to its transportation to the site of construction. The modules may often be required to be broken down into smaller sizes for ease of transportation. Modularization usually involves more than one trade.

Prefabrication: This usually involves a single skill or trade and is generally defined as a production process, which normally takes place at a specialized factory where different materials are combined to form the component of an end-product. As long as the component is manufactured at a factory and is not a whole system, it is regarded as prefabricated.

Preassembly: By definition, preassembly is the combination of various materials and prefabricated components at a separate facility before installation as a single unit. This installation is carried out similar to the process of modularization in which the manufactured components are assembled close to the site, followed by on-site installment.

Commonly regarded as a combination of modularization and prefabrication, preassembly usually involves works from various crafts and parts of different systems.

Industrialization: This term refers to an inclusion of all three aforementioned categories of offsite construction. Industrialization is based on the concept of manufacturing and is defined as the procurement of technology, equipment and facilities in order to increase productivity reduce manual labor and improve production quality.

Further, Kok(2010) identified several definitions of prefabrication from previous literature. One such definition states that a prefabricated home: is one having walls, partitions, floors, ceiling and roof composed of sections of panels varying in size which have been fabricated in a factory prior to erection on the building foundation. This is in contrast to the conventionally built home which is constructed piece by piece on the site. He also defines prefabrication as a manufacturing process taking place at a specialized facility, in which various materials are joined to form a components part of final installation and finally a prefabricated building is one: which consists of elements that are manufactured or fabricated in a location (off site) which is not its final destination. They are transported to the site, and connected one to another to form a complete structure. Usually the elements are limited by size of transport vehicles and lifting equipment.

Generally, IBS would be said to be a system that comprises prefabricated elements manufactured offsite and then transported to the on-site location for installation, or simply manufactured and installed on-site, thus eliminating the need for transportation

.Industrialization is often referred to as offsite production, prefabrication, automated construction, preassembly, and offsite manufacture (Edima, 2012).

2.2. Building Construction System

Edima also noted Warswaski(1999) that there is no single system of building construction classification as opinionated by The author believed that such a classification was relative to the user or producer and varied from one to another, usually based on the choice of construction technology. Based on this, it was asserted that four systems could be distinguished as determined by the main structural and enveloping materials of the building: timber, steel, cast in-situ concrete, and precast concrete systems. He also suggested that for further classification, the geometric configuration of the components of the building's mainframe could be used as follows: linear or skeletal system (beams and columns); planar panel system; and three-dimensional (box).

Back in 1977, Majzub recommended the use of the relative weights of building components as the basis for the classification of building systems as Edima recognized. The argument for this was that classification by weight significantly impacted the transportability, method of production and on-site erection of components. However, this system was found by (Thanoonet.al, 2003) to have one limitation: its inadequacy to categorize complex systems of two or more construction methods.

In recent study by Abdul Kadiret et al. (2006), two main types of building systems are proposed: Conventional Building system (CBS) and Industrial Buildings System (IBS). The CBS is sub-divided into two main components: the structural system and the non-structural system. The former consists of cast in-situ column-beam-slab-frames while the latter includes the use of brick and plaster as infill material.

On the other hand, three building classifications are proffered by Kok (2010) primarily based on their methods of construction: conventional, cast in-situ, and prefabrication construction methods. He defines CBS as the on-site prefabrication of a building's components using the methods of installation of timber or plywood formwork, steel reinforcement and in-situ casting. Cast in-situ construction method involves on-site implementation of formwork, a method that can be retrofitted for all types of building construction. Prefabrication method is defined as the process of manufacturing industrialized or precast construction components, offsite (in a factory), before delivery for erected on the actual construction site.

However, Abdul Kadar et al (2006) state that a fully prefabricated system could be one of two categories depending on the site of production: on-site or off-site (factory-produced). They argue that on- site prefabrication differs from cast in-situ method. Here, the on-site system means that structural building components are cast in the site before being erected at the actual location. In their opinion, the on-site system also provides more advantage over the cast in-situ method. Based on earlier works, three main classifications of building systems have been identified: conventional, cast in-situ and prefabricated building systems.

2.2.1. Conventional Building System (CBS)

In Kok's (2010) definition, CBS is the on-site prefabrication of a building's components using the methods of installation of timber or plywood formwork, steel reinforcement and in-situ casting. But, Abdul Kadir et al (2006) break down CBS into two components: the structural and non-structural. The structural component includes column-beam-slab frames, which are cast in-situ. This component involves a four-step process. The timber formwork and scaffolding are erected; this is followed by the erection of the steel bars; the fresh concrete is poured into the formwork, and finally the formwork and scaffolding are dismantled.

These operations are tiresome, labor-intensive, and demand considerable on-site coordination. The other, the non-structural component, comprises non-structural brick and plaster used for infill. The CBS has the advantages of ease of transportation of its wet trade; flexibility in terms of geometry of buildings; and easy adoption of last-minute changes. However, its downsides are in its 'exposed' production environment; extra time required for the drying of wet concrete; and the need for additional temporary works. Another issue is the high cost of time, labor, materials, transportation and low construction speed, especially because of the use of wooden formwork in the traditional method of construction as noted in (Kok, 2010).

2.2.2 Cast In-Situ Building System

This construction system is one in which the formwork is implemented on the construction site. Technically, it is applicable to all kinds of building constructions. Cast in-situ is an improvisation of traditional formworks, aimed at the reduction and elimination of conventional on-site trades such as timber formwork, plastering and brickwork with aluminum, steel or fiberglass. This transition has proved to be cost-effective, thus making the cast in-situ method appropriate for constructions involving the repetitive use of formwork such as mass-produced housing units, as the usage is carried out with the least possible waste. This is an added edge over the traditional timber formwork method which can only be utilized twice or three times. In addition, steel formwork provides ease of erection and dismantling, thus requiring low-skill labor. With careful planning, speed, precision, reduced overall cost and optimized productivity and durability of the prefabricated construction are achievable, Abdul Kadir et al (2006) and Kok (2010).

2.2.3 Prefabricated Systems

The widely accepted definition of prefabrication is a process involving the manufacture of industrialized or precast construction components of various dimensions at a factory, before delivery to a construction site for assembly. However, as previously stated, the casting or manufacture of the structural elements could be carried out at the construction site before its actual erection. Therefore, a wholly prefabricated system primarily falls under two categories: off-site- and on-site prefabricated systems.

The on-site system provided even greater time and cost savings and allows for larger quantities of mass-produced units than the cast in-situ system. Secondarily, a composite system exists which involves the casting of some elements of a structure on-site, while others are manufactured at the factory. This is referred to as the composite prefabricated system. Typically produced precast elements include in-filled walls, floor slabs, bathroom and Staircase units, to be subsequently incorporated into the already cast in-situ columns, beams and the main units of the structure in question.

Generally, prefabrication is a convenient construction system which allows flexibility in production as long as the required elements are delivered as scheduled. One of the major advantages of prefabrication is minimization of construction waste as well as time, labor and cost savings. Although significantly less labor intensive and time consuming than CBS, studies show that it is yet to be fully embraced as the preferred system of building construction.

2.3 .Prefabricated Components, Manufacture and Assembly Process

The most commonly used prefabricated components are the precast concrete components. Precast concrete is defined as concrete which is cast in one place, for intended use in another place, and is usually mobile. Most of the production of components is carried out in a specialist factory, except in cases where factors such as economy, geography, production scale and difficulty of access, require the components to be cast on or close to the construction site. Regardless of production location, the same managerial, supervisory and operational skills are employed. This section is dedicated to all processes involved in the production of precast units, from design considerations through manufacturing to on-site delivery and assembly.

The success of a prefabrication operation lies in the integration of all the concerned building professionals – architects, engineers, contractors, sub-contractors and clients. In order to achieve total building performance, these professionals must undergo a fundamental mind-set change from the conventional way of project execution.

The conventional here being that consultants are more interested in the needs of clients, regulations, soundness of design and functionality while clients are more concerned with cost and final product; and contractors main concern is the building process (Building and Construction Authority, 2006) noted in (BCA,2010). The disciplinary differences between prefabrication and in-situ concrete are seen in the opportunities for mechanization and quality and output controls, according to Edima.

The parts of a building to be prefabricated are grouped as follows: the building's shell (which include its envelope and structural parts) and its finish works (which include doors and windows, exterior finish, insulation, electrical and plumbing elements).

There are two main approaches to the prefabrication of heavyweight components: the planar partition approach and three-dimensional approach. The planar approach involves the prefabrication, transportation and on-site assembly of walls and floor slabs, while the three-dimensional approach refers to the partitioning of the building (interior finishes inclusive) into three-dimensional spatial units. Planar components could be of consistent modular room size. The elements of the room conform to its interior layout spaces and so their connecting joints are well-hidden – an architectural plus in houses and analogous buildings. The planar approach is the predominant approach as it gives more room for design flexibility, easier transportation and has no need for heavy lifting equipment and the study will focus on this approach.

2.3.1 Precasting Design Considerations

Structurally, the difference between conventional construction and prefabrication is structural continuity. In the case of the former, continuity is inherent and flows naturally during the construction process. For the latter, conscious effort needs to be made to ensure this continuity begins with the connection of the precast elements; the connections act as bridges between the elements. Thus, safety and stability should be the watchwords at all stages of construction, in order to achieve a stable structural system. The successful implementation of the multi-disciplinary techniques of precasting requires careful planning and synchronization among the concerned disciplines (engineers, architects, general contractors and precast concrete specialist subcontractors), through all design stages.

The decision to use prefabrication in construction needs to be made at the earliest of design phases in order to allow for adequate coordination – lead-time to allow for factory set up of the precast elements should be sufficient. The prefabrication organization should be part of the decision-making process to ensure design practicality and simplify production. Design considerations are required to achieve high quality precast components.

They include dimension and shape of precast elements; concrete components; moulds; reinforcements; joints and connections; loads; lifting and handling devices; transportation and storage systems. Feasibility studies are required to assess the capacities of the available transportation systems and on-site storage space, to ensure adequacy. Compulsorily, the overall construction process must be properly established during the early design stages. The design requirements for the erection or assembly of the precast components must be done sequentially, with maximum tolerance.

Product samples should be set up to test product characteristics and quality (both on-site and offsite) for conformity and standardization. Finally, and most importantly, last-minute design changes should be avoided as much as possible, as they inevitably lead to increased expenses (Baldwin et al, 2009) and (Building and Construction Authority, 2010).

2.3.2 Precast Design Procedures

There are four phases of designs which must be undertaken by the structural engineer in the precast production process:

1. Load assessment: load estimates and tables must be set up.
2. Calculation model: this phase includes:

- ❖ Definition of structural system
- ❖ Description of potential load path
- ❖ Assessment of the stiffness of elements and joints
- ❖ Method of execution and load combinations

3. Structural analysis: steps in this phase are:

- ❖ Determination of the elements and joints' loads
- ❖ Evaluation of the carrying capacity or strength of cross-sections, joints and materials
- ❖ Comparison of loads and resistances.

4. Documentation: specification, shop and assembly drawings, and calculations.

2.3.3 Prefabricated Construction Process

Once the design procedure for the components is completed, each component has to undergo the following processes as outlined by (Chan and Hu, 2001):

- Concrete mixing and movement from the mixing point to the mould;
- Setting of moulds: the moulds are cleaned and oiled and the side frames are fastened;

- Placement of fixtures, reinforcements, electrical components and such as will form part of the components;
- Casting: the concrete is poured, compacted and leveled;
- Curing; naturally or artificially (by heating);
- De-molding; the side frames are stripped and the components are taken out;
- Finishing, patching and repairing of the components;
- Placement of the finished components in the stockyard for delivery strength; and
- Transportation of the components to the assembly site.
- Erection and installation of components on site and assess the integrity of each components.

2.4Requirements of Precast Concrete in Building Construction

Precast concrete technology is widely used in the industry to support build ability and improve construction productivity. Such technology also results in better quality workmanship as the precast elements are manufactured under controlled factory conditions before its installation at site. This section highlights the better workmanship quality that can be achieved when precast technology is integrated in the design of the building.

2.4.1 Dimensional Accuracy

Precast concrete elements achieve superior dimensional tolerances and finished concrete surfaces compared to cast in-situ concrete. This is largely due to the favorable environment in factories where these elements are produced and the stringent quality control measures taken to meet specified or national standards during production.

In traditional brickwork construction, it is a challenge to ensure consistency in forming openings for windows and door frames. Any excessive gaps or improper filling of such gaps may lead to water seepage at the frame and wall joints.

2.4.2 Better Quality Critical Elements

Pre casting is often the solution to quality problems when there are difficulties in executing the particular type of work in-situ. Staircases, refuse chutes and lift walls are examples where formwork, rebar placement and provisions for openings often pose considerable challenges leading to grout loss, inconsistent joints, surface damages and imperfections. Using pre-cast elements for these components, such defects can be reduced.

2.4.3 Better Quality Architectural Elements

Precast architectural elements such as facades, fascia and gable end walls, parapets, sunshades, secondary roofing panels, bay windows, etc can be used instead of wet in-situ works to achieve correct dimensional tolerances and better quality finish.

2.4.4 All-In-One Components

In total precast concrete systems, architectural elements can also perform their structural functions. It therefore reduces the number of construction operations and trades. Combining architectural and structural members lead to better organized design and construction.

2.4.5 Design Flexibility

Precast components can be custom made to match design requirements. Complex shapes, sizes and specific technical requirements can be easily fabricated in precast plant. Without such prefabrication, complex designs may be difficult to build or the desired quality hard to achieve on-site using conventional construction. Pre casting allows greater design flexibility and repeated use of similar shapes and sizes lead to better economy.

2.4.6 Speed and Productivity

Traditional concrete construction involves many trades such as formwork, rebar and concreting. These activities have to be carefully planned and co-ordinate in a non-conducive site environment which affects the speed of construction and quality of output. In contrast, pre casting is carried out in controlled factory environment leading to ease of production and better quality output.

2.4.7 Better Quality External Wall

Alignment, verticality and surface finish of external elements are critical areas in building facade. Factory made precast wall panels require minimal surface preparation before final finish. Scaffolding is generally not required for the finishing works. This makes the construction site tidier and the works can be carried out faster, apart from savings in scaffolding cost. Typical quality problems in traditional plastered external walls such as hollowness, plaster waviness and cracks can be avoided when precast external facade system is used.

2.5 Benefits of Using Precast Concrete elements

Generally, the advantages of prefabrication are tied to the reduction of construction costs of projects. As time and labor are saved while productivity is increased, cost savings are achieved. Several authors such as (Polat, 2010) endorse the implementation of prefabricated elements and studies carried out to determine the true benefits of prefabrication over traditional construction methods.

Based on studies carried out on houses, hotels, hospitals and other buildings of different functionalities, (Rogan et al, 2000) found the following benefits provided by prefabrication in comparison to conventional construction: improved quality, increased construction time by 50%, waste reductions of 70%, up to 10% savings in project capital costs, and the advantage of JIT delivery to the site. After a thorough study, the economic and technical specifications of the components were arrived at that would meet the requirements of low-income earners, and subsequently middle- and high-income earners and were found to be satisfactory.

The collective conclusions presented the advantages of prefabrication to be short build times; superior quality by pre-design and quality control, low weight in that prefabricated construction is 70% less than the weight of traditional construction; environmentally less sensitive which is less waste and less disruptions of installations, usability on infill sites such as roof top-extensions, reduction of labor requirement; safer construction; cheaper professional fees, standardization is simpler and less specialized design input needs and the much-needed economies of scale.

2.5.1. Overall Cost Reduction

The primary advantage of prefabrication recognized by many researchers is the overall reduction of project cost as compared to the conventional method of construction. If more work is carried out offsite than on-site, then the risk of costly delays due to weather and harsh on-site conditions would be avoided. The need for local labor, which is mostly incompetent or expensive, would be significantly reduced. In addition, worker congestion and on-site complication could be avoided, allowing for increased productivity and reduced costs.

Cost savings from the use of prefabricated elements are the reduction on the need for site preliminaries and quicker return on investments (ROI) to the client, loss of profitability in the case of extension of existing facilities, and construction schedule predictability. It is known that prefabrication provides 50% savings in time which in turn leads to a beneficial proportionate savings in the cost of these preliminaries. Huanga et al. (2004*)*, showed that the time taken to erect formworks for a reinforced concrete building project amounts to a third of the total concrete cost or 15% in terms of the overall construction cost. By replacing traditional formwork construction with prefabricated form sets, cost is effectively optimized as the form sets could be reused within the same project or between projects and also minimizing material loss.

In their report on the cost analysis, (Baldwin et al.,2009)stated that by including manufacturing and material costs, offsite and on-site inspection costs, and erection costs of prefabricated components, the cost of prefabrication is between 25% and 35% more than the cost of traditional construction. However, prefabrication becomes more competitive when: 30% production savings which results in less labor requirements on-site; savings in materials as a result of reduced formwork and false work needs; and optimized use of reinforcement in factory production which eliminates on-site concrete dumping. They also noted that precast floor slabs save 28% and 45% while precast pre stressed concrete beams save 60% and 65%, of the quantities of concrete and steel required, respectively, for cast-in-situ construction.

Factory production and products pre-testing of typical units, such as those for bedrooms and bathrooms, offer the benefits of speed and quality. Design is greatly improved upon, more investments are made in the production, stringent quality assurance measures are implemented variation in design is provided at optimal costs, and waste is reduced as design repetition is avoided. Prefabrication is an ideal solution for constructing a residential building due to the production of similar types of elements repeatedly in bulk, thus reducing cost (B. Raghavendra Ket al, 2016*)*.

Pre-cast concrete provides durability, flexibility and sound durability with cost efficiency. Cost of pre-cast may vary with the type and the size of construction. For a small project the cost of prefabricated increases due to no production of elements in bulk. However, for bigger projects the cost may decrease significantly. The following table shows percentage of cost savings in precast elements compared to other elements.

Table2.1 Cost saving in precast elements **(B. Raghavendra K)**

Activity	Footing cost	Column co	Beam cost	Slab Cost	Total
Steel frame with Composite deck floor	5.6	31.9	167.76	70.32	274.48
Precast frame with precast concrete floor	3.5	10.53	27.68	55.74	97.45
Steel frame with precast concrete floor(combined)	5.6	31.9	167.76	37.72	242.98

As noted by B. Raghavendra K, the above table shows construction cost of footing, columns, beams and slab, which are made by using steel frame, precast frame and combination of both. The above table showed that precast frame with precast concrete floor is more economical. The direct cost of the precast frame with precast concrete floor comes out to be lesser percentage than the cost of steel frame with composite deck floor.

2.5.2 Time Savings

Time is a critical resource in all construction activities. Time provides competitive advantage as the ability to deliver products faster than competitors means higher job consideration value of contractors. The adoption of JIT philosophy provides this advantage; speed and efficiency have become associated with prefabrication and industrialization of buildings. The production and delivery of the right quantities of products and the right quality for offsite casting and on-site assembly at just the right time enhances the productive, buildable and logistical edge for building contractors. As opposed to the conventional methods where construction activities are performed in an austerely linear order, prefabrication allows for multiple activities to be carried out simultaneously in different locations, lessening the duration of construction (Haas et al, 2000).

He also explained that the speed of construction that prefabrication provides ranges between 5% and 10% of the total cost of construction measured in terms of time saved on site, compared to the traditional construction method. With regards to the construction of formwork, the use of traditionally constructed formwork is highly time-consuming. This is because in addition to the number of mandatory man hours required for the erection of these formworks, it is necessary to put in more hours in order to further finish the concrete surfaces after stripping. However, with the use of modular formwork systems, there is less need for further finishing due to the smoothness of the surface of the formwork, the time required for erection is considerably shortened and skilled labor is saved (Huanga et al, 2004).

Compared to cast-in-situ method, the precast method consumes less time because the prepared materials and elements are delivered just in time and placed on site which reduces unnecessary handling and equipment use. This allows other trades to begin work more quickly which speeds up the construction time and is more economical with fewer disturbances for the surrounding. Cast-in-situ method of concreting requires a lot of time because concrete requires minimum 28 days to achieve 99% strength of its total strength stated in (N.Dineshet al.) as (B. Raghavendra et al) noted. The table below also shows the time saved by using the prefabricated elements compared to convention construction.

Table2.2. Time comparison of precast elements and convention construction (B. Raghavendra K et al).

No	Descriptions (Summary Work)	Duration in days	
		Prefabrication Construction	Conventional Construction
1	Sub Structure- (Site Cleanin earthwork,Foundation, Basement, Soil Filing)	22	22
2	Super Structure-(Wall Panel Framing and roofing slab	12	52
3	Finishing Work-(Electrical, Plumbin Painting, Tiling and Windows)	31	54
`	Total Duration	65	128

According to table 2.2, it shows that the time required in prefabricated construction is almost half of that of the conventional methods of construction for the same construction. In their idea, conventional method of construction is almost twice longer than that of prefabricated construction methods.

2.5.3 Safe and Controlled Construction Environment

The construction environment is generally considered unclean, unsafe, untidy, hazardous, vulnerable and accident-prone due to the carelessness of construction workers and a lack of safety and health awareness (Kok, 2010). One of the major causes of causalities on-site is the construction of the false work required for the erection of formwork. On the other hand, modular formwork has higher strength and hence the task of pouring concrete is considerably less risky, and so the safety of workers is more assured (Huanga et al, 2004).

One notable achievement which prefabricated building parts provide is a safer and more productive working environment. There is a significant improvement in the overall project safety as a result of less risk of worker accidents, thus saving on the set-back of potentially lost time due to the prevalent severity of the working conditions of on-site jobs. As Haas et al (2000) also noted, Job conditions are not dictated by the weather, fire, work progresses uninterrupted and productivity level remains high, providing a truly considerable advantage over traditional construction.

Chan et al (2004) assert the use of prefabrication in recent times in the construction industry, as it has been seen to boost site safety by providing a cleaner, tidier work environment. Kok (2010) also noted for prefabrication in relation to the advantage it provides construction stakeholders - a better more controlled, more organized environment which enhances health, safety and welfare.

2.5.4 Quality Improvement

Prefabrication provides better quality of work than is obtainable through on-site construction. This is attributed to the controlled working conditions in the production factory, the repetitions of processes and activities as well as the use of automated equipment (Haas et al, 2000).

According to Rogan et al (2000), since quality is a highly critical issue to clients in their concern for the post-construction operation of their finished buildings, the implementation of prefabrication system means pre-installation trials of products can be carried out to ensure quality and client satisfaction, especially with regards to high-service units such as elevators, plant rooms and kitchens. The need for the 'call-backs' cost that is usually included in the bill of quantities of conventional construction procedures is reduced considerably.

2.5.5 Productivity

B. Raghavendra K et al (2016) noted that labor productivity of a structure through pre-cast system is more than that of Cast-in-situ system. The time required to install structural components using prefabricated is less compared to cast in situ method. The variability of the productivity in pre-cast method is also small, which means that it has more consistent productivity values over a period. The loss of efficiency in prefabricated method is less as a result of smaller work force at the pre-cast construction sites. The cost incurred in the project is affected by the labor efficiency.

The table below represents the percentage of loss of labor productivity of conventional and prefabricated construction methods.

Table2.3. Percentage of loss of labor productivity (B. Raghavendra K et al, 2016)

No	Descriptions	Consumption (Percentage)		percentage Difference
		Conventional	Prefabricated	
1	Concrete	100	80	20
2	steel	100	70	30
3	Manpower	100	50	50
4	Waste	100	50	50

As shown in table 2.3, percentage of wastage of labor productivity and consumption of materials in prefabricated construction is less than that of conventional methods of construction for different parameters.

2.5.6 Environmental Impact

With less need for field labor and on-site activities, the impact of construction on the environment is positively reduced. This advantage is especially significant considering the negative environmental impacts associated with the construction industry, which are particularly attributed to the traditional construction processes (Haas et al, 2000).

Rogan et al (2000) give detailed benefits of the use of prefabrication to the construction of buildings in terms of construction operation, building use and subsequent re-use. Prefabrication saves the environment when compared to traditional construction methods. In terms of operation, energy used for product manufacture, construction and service operations is comparatively lesser. These advantages are part of the benefits of speedy construction which prefabrication provides, in that shorter construction period means less environmental impact.

Mainly, there is greater efficiency and economy in the use of materials than can be achieved with conventional construction. Moreover, factory production means waste is substantially reduced, and the need for landfill is lessened by about 30% of that of conventional construction, as well as the environmental damage due to on-site packaging and use of materials. Schedule for delivery and installation of modular units can be programmed to avoid traffic and site working constraints, and even delivery of a large number of small quantities of materials is reduced. There is less noise pollution and other environmental nuisances to nearby buildings since the main construction operations are carried out elsewhere, in a factory. With regards to the use of the buildings, high performance is an important benefit of prefabricated construction.

The production of prefabricated concrete components requires far less cement per volume of concrete for similar cast-in-place productions, due to enhanced quality control measures. Aye et al (2012) carried out comparative studies on the embodied energy and carbon contents of traditional and prefabrication processes. They found that prefabrication provided energy savings by as much as 17% of Carbon dioxide emissions and 32% of embodied energy. According to the Parliamentary Office of Science and Technology (UK,2003), prefabricated parts generally require less heating energy as a result of increased insulation levels in their walls and roofs, and also less air leakage, due to the manner of construction of the prefabricated building components.

Finally, prefabricated buildings are much easier to expand or reduce, than traditionally constructed buildings. At reasonable prices, prefabricated parts are also much easier to relocate, affording lower energy costs for their dismantling, reduced long-term use of scarce resources, and importantly, no material wastage.

2.5.7 Waste Reduction

It is known that the construction industry is one of the main generators of waste and a huge percentage is attributed to on-site concreting.

In order to achieve a significant reduction of waste, it is therefore paramount to limit on-site concreting processes during construction. Prefabrication and pre casting provide significant opportunities for the reduction of waste of resources in construction. Pre casting has been said to encourage waste minimization in the construction industry through design innovation. Less timber formwork, less wet trades on-site, reduced water pollution, from construction activities and general improvement in waste management and disposal increase environmental merits. Factory production ensures a cleaner, safer setting for works resulting in more economic use of materials. Similarly, pre casting improves quality of components thereby standardization is ensured and the occurrence of waste is minimized (Chen et al, 2010).

According to (Tam et al, 2005), excessive construction waste is as a result of wet-trade construction such as plastering, bricklaying and in-situ concrete works. Their reasons for the wastes are inconsistency in design, poor workmanship, installed losses, in-transport damage, cutting and over-ordering, all of which can be effectively mitigated by the adoption of prefabrication (Chan et al, 2004).The result of their study on waste reduction value of prefabrication showed a 56% construction waste reduction, in addition to 20% saving on construction time, and over 40% reduction in water consumption.

In spite of the highly praised advantage of waste reduction and minimization provided by prefabrication, (Dubois and Gadde,2002) argue that prefabrication is not as much a waste saver and argue that prefabrication causes waste due to overproduction. The production at the point of use that is only when required will eliminate this problem.

2.5.8 Innovation and Industrialization

According to (Dubois and Gadde), the process of learning and innovation is hardly a success in the traditional construction industry because each house is treated as a pilot model for a design that never had any runs. Innovation in construction is said to be the process of generating new ideas for new components with intrinsic functional, economic and technological values. The need for innovation has been pressed upon building professionals as a result of the requirements for increased quality of buildings, tight schedules, safety and the regulations for environmental protection. As such, more and more contractors are embracing prefabrication of building components.

Prefabrication is associated with better product delivery in terms of mass production, factory conditions, offsite production, standardization, innovative technology and equipment. Prefabrication has become much more than just the industrialization of buildings and building technologies. It is reengineering, industrialization, concurrent engineering and value-adding (Chan et al, 2004).

To summarize, (Tam et al. 2007) carried out a survey on the significance of the benefits of the adoption of prefabrication. The results of the survey showed that according to its participants, better supervision on improving the quality of prefabricated products was regarded as the most significant benefit of better supervision because of the pre-installation trials and inspection of the products. This was followed by early standardization of design layouts and overall cost reductions as second and third in significance, and time savings is the fourth in the rank of benefits of prefabrication.

2.6 Limitation of precast concrete Parts for adoption

In spite of the praise-worthiness of prefabrication as a preferable construction method, it poses a certain disadvantage which has rendered it disagreeable as noted by several authors. This single disadvantage is cost. The cost competitiveness of prefabrication in comparison to other systems is seen at the initial mass production stage, where initial cost of form-making is high. However, once constructed, every additional component becomes much cheaper.

The higher costs are also incurred from shipping, engineering and installation of the prefabricated components, particularly when steel frames are used (West, 2011).The cost savings in production may be replaced by the cost of transportation of manufactured components, particularly in the case of large modularized sections that must be conveyed over long distances. Size therefore becomes a constraint to the method of transportation which implies cost and schedule considerations. As a result, certain engineering aspects need to be pre-approved before construction is fully implemented, such as finalization of design work and wide-range planning, as well as interference analysis.

Although this may cause limitations in the flexibility of rework - as a result of the difficulty associated with design modifications once the project has begun –(Haas et al,2000) argue that it could be beneficial in the sense of better scope control and an overall improved project performance.

Prefabricated houses are more affordable than traditional houses, as the controlled factory environment means production is carried out at a faster pace, meaning less time is required, materials are saved and labor is reduced. All of this translates to less cost. However, the initial or upfront cost demanded by the prefabricated manufacturers is seen to be quite high and as such the cost advantage of prefabrication is reduced. Another aspect of cost ineffectiveness is in the use of non-standard units due to client requirements, which may actually increase production costs (Rogan et al., 2000).

2.6.1 Influence of Traditional Culture

Stephen(2008) point out interestingly that in applying lean principles to construction, the scarcity of error proofing, maintenance of equipment and standardization of floor works in the industrialized building system shows that the prefabrication is clearly still influenced by a production culture bearing the marks of traditional construction techniques. Their opinion is that the mentality that construction professionals bring from the traditional background into the industrialized system is a constraint and thus the application of lean construction principles needs careful implementation.

They agree however that this mentality is not entirely a constraint; the traditional culture brings to the table flexible teams that take responsibility for themselves, is important for lean culture. There are no formal criteria backing the decision to implement prefabrication in building projects, besides the simple and holistic evaluation methods that consider, Labor, transportation and materials costs when comparing construction methods (Chen et al., 2010). These methods are deemed for some customers as they do not take into account long-term issues such as environmental impact, energy consumption and life cycle costs.

Arguably, recent studies on the advantages of prefabrication carry out extensive life cycle and environmental analyses of the impacts of prefabrication. Chen et al.(2010) argue that prefabrication is not always the only suitable available option for consideration for a construction project, there may be several other viable choices depending on the type of project. They further argue that prefabrication is not necessarily always a better option than conventional construction methods, pointing out that precast technology could be disadvantageous in terms of such problems as delays in production and erection schedule and significant cost overruns. They propose that holistic criteria are needed to truly determine the appropriateness of any construction method and also the stimulation of the use of prefabrication for a particular building project.

2.6.2 Standard Equals Boring

Standardization means standard buildings were one of the most popular topics during the Syria Research (Gibb, 2001). Classic examples of buildings whose standardized components were used to produce effective customized solutions include the Charles Eames house and the Georgian residential design style. These buildings may be deemed boring in the architectural sense but then aesthetic is clearly a subjective issue, and he points out these are houses people aspire to own, and boring is further from their minds than anything else.

The argument here is that although the individual components are standardized, the building as a whole should be a representation of customization, that it must provide variation. He established that these modern specifications turn out to be mere adaptations from earlier projects and concludes that by focusing on design excellence, standardization and pre-assembly could produce buildings that are innovative and exciting, and certainly not boring.

Additionally, one impeding criterion of the increased use of prefabrication is the bad image attached to buildings constructed with precast concrete elements (Girmscheid and Kröcher, 2007). The highly negative influence of the post-war perception of prefabricated houses on house buyers poses a strong resistance to any construction innovation that presents houses in a different way than what a traditional house is supposed to look like, including prefabrication. This resistance to change the negative image of prefabrication is also seen among industry professionals in the UK where the refusal to accept innovation has proven to be a huge set back (Goodier and Gibb, 2007).

In order to please the client, the builder is ready to sacrifice build ability for aesthetics and uniqueness of the building. The Future Homes project was believed to signify the arrival of a fully factory-based housing approach that took full advantage of the digital technologies of today. They noted that by incorporating visualization and mass-customization, it was hoped that the greatest apprehension – the association of factory-based housing with styles that lacked taste and were unable to express custom or culture – would be avoided (Wing and Atkins, 2002).

2.6.3 Knowledge Gap

One of the difficulties of the application of prefabrication is knowing the required use of standardized components to manufacture buildings both aesthetically and functionally. Therefore, the needs of experts and professionals, the needs of standard manuals and high skilled man power are the major issues for the development of knowledge gap in prefabricated construction. Moreover, this study focuses on the identification of major problems on precast construction and it also provides a clear awareness on the area in order to fill the gap of using prefabricated components in construction projects.

In the competition between precast and monolithic structures, prefabrication gains an ever increasing prominence because it is accompanied by the improvement of quality, while the requirement in materials, working time and cost shows a decreased tendency.

Goodier and Gibb (2007) carried out a survey to determine the barriers to prefabrication. They basically note that there is a discrepancy or gap in the understanding and knowledge of prefabrication. Apparently, this knowledge gap - customers believing that they are aware on one hand and suppliers believing that they are not – is often a cause of frustration for suppliers, most of whom assert that there is a general lack of understanding of the advantages of prefabrication in all aspects of the construction industry. Further frustration results from customers who regularly utilize precast concrete without any awareness or appreciation of this as a form of prefabrication. It was suggested that an improvement in communication, education and experience would bring clients, designers and suppliers closer together, and bridge the knowledge gap.

Blismas et al. (2005) opinionated that when viewed holistically, knowledge was the one constraint that had the biggest influence on all the other constraints of prefabrication. The limited experience of project teams in handling prefabrication is a hindrance to its widespread application. For instance, with experience in prefabrication, more options for its use could be considered for implementation during construction projects; product and process reuse would be more easily determined based on knowledge and experience gained from earlier prefabrication projects. Because contractors are used to submitting tenders for conventional construction projects, the same methods are applied for prefabrication projects.

The issue here is that unlike the case for conventional works where design can be changed during the erection of the structure, prefabrication requires conclusive design and planning before execution and the decision to include the use of prefabricated units in projects usually comes at a much later execution phase. Thus, tenders for conventional on-site works prevent the widespread use of prefabricated units. Construction professionals need to be made aware that tenders for prefabricated units are more beneficial than those for conventional works.

Girmscheid and Kröcher (2007) suggested that the foundation of an industrial institution to bridge knowledge gaps and provide decision-making aids, innovative performance parameters and elimination of the strict requirement of a certain number of prefabricated elements to be produced at a given time for a project. Chan et al. (2004) advocated for not just the acquisition of knowledge but also its proper management in order to achieve competitive advantage and improved performance among contractors. They state that to manage knowledge is to identify, optimize and actively manage intellectual assets for value creation, increased productivity and sustained competitive advantage. The study of this thesis focus on improving knowledge gap for prefabricated construction in the country.

2.7 Problems of Prefabricated Concrete components

Wei (2006) endorses prefabrication as one of the means of effective waste management. (Blismas et al., 2005) also states that according to the Egan Report supply-chain partnerships, standardization and prefabrication were said to play major roles in the improvement of construction processes. In spite of these and the aforementioned advantages of prefabrication, certain constraints to its successful application have been identified by numerous reports such as those of (Lovell and Smith, 2010) and (Blismas et al., 2005).

Blismaset al.(2005) expounding on the causes of the constraints associating the negative characteristics in the construction industry: disjointedness, underachievement, work at low profitability, almost non-existent capital investment in training and research and development and in general, a low-level performance satisfaction of clients.

Tam et al. (2007) analyzed the hindrances to the adoption of prefabrication and discovered ten factors responsible for this: design inflexibility; higher initial construction cost; more time consumption during initial design stages; lack of background research information; lack of experienced contractors; limited space for prefabricated components; inconsideration of the advantages of on-site conventional construction methods; possible leakage problems during joining of prefabricated components; lack of demand for prefabricated building components; aesthetic building monotones. Among all these constraints, design flexibility ranked as the worst constraint, while cost ranked fourth. This is unlike other studies in which the perceived higher construction cost was said to be the main reason for the low level of implementation of prefabrication.

2.7.1 Higher initial investment Cost

It is the development cost of the factory which includes the cost of molds, equipment's and machineries and other additional cost for initial investment of the company, excluding the production and the construction stage of prefabricated elements.

Pan and Sid well (2011) noted that the widely-held perspective on prefabricated parts as a higher cost of construction than conventional methods of construction, they observed that prefabrication, like every other innovative technology, is trapped under the caption of high investment cost.

These perceptions on the higher costs of prefabrication seem to be deeply rooted in the mentality of construction professionals. In their study, they observed that the most critical constraint is seen as the higher cost, in addition to the lack of public data and information which has been identified as the most inhibiting factor to the increased use of prefabrication. The general belief is that innovative technology in the construction industry is cost-intensive with indefinite returns, and due to the peculiar nature of the construction industry, is a poor competitor for direct profits associated with conventional construction methods.

Further, they also stated that the cost-effective argument against prefabrication is (7-10%) increase in construction cost according to industry sources, in spite of the stated advantage of reduced costs.

The reason for this higher cost is difficult to determine due to the commercial confidentiality of most projects' financial information, and also because of the widely varied costs of traditional construction. The greatest cost constraints of prefabrication can be summarized into the following four factors:

- The capacity of the concept of cost as a barrier.
- The resultant real or perceived greater cost of implementing prefabrication and offsite technologies as compared to traditional construction methods.
- The absence of data and information of offsite construction cost.
- Scarcity of data on the cost reduction and increased cost effectiveness of prefabrication.

Using a simple cost basis, prefabrication is deemed to appear more expensive, while a more holistic approach exposes its benefits which are not easily monetized. These cost factors are the reason for the reluctance expressed by builders and developers to adopt prefabrication in spite of the cost-unrelated and life cycle cost benefits. Thus, cost evaluation comparison systems are inadequate (Blismas et al., 2005).They carried out a study in which they successfully dispelled this myth by proving that the use of precast concrete of medium to high-rise buildings provided cost savings that ranged between (11-32%). In addition, the adoption, development and innovation of cross-wall technology continuously saved on costs up to (25%) in apartment buildings as well as improved cost effectiveness in high rise buildings. They however propose that sustenance of the cost reduction benefits of prefabrication is neither automatic nor just a result of long-term use, but requires organizations to be committed and continuously explore offsite technologies, along with their supply chains, otherwise the myth would eventually become a reality.

2.7.2 Connections and Joints

ACI or BS codes recommend considering all conditions starting from initial production till installation and completion of structure, and provide strength requirements for various connections .The experimental study demonstrated that it is possible to design and construct precast beam column connections, where beams and columns are joined with ductile connecting elements, to withstand severe inelastic deformations resulting from earthquake forces.

It was concluded from the experimental program that the large forces required to be resisted by the perimeter lateral-force resisting frames resulted in large beam and column sizes and large amounts of reinforcement that made detailing of the members extremely difficult. Due to the jointed nature of precast frames, special attention must be paid to the stiffness of the structure, in other words, the weak joints of prefabricated concrete part frames can easily be disintegrated from members of beams &columns (CPPCC, 2016).

Massey and Megget (1992) compiled a document on the architectural design for earthquakes, a guide to the design of non-structural elements as (CPPCC, 2016) mentioned. The document contains sections on measuring earthquakes, configurations, structures and external walls, external wall types, windows and curtain walls, internal elements, partitions, suspended ceilings. In the section on external wall types, facing materials are defined as those which clad the main structure but should be effectively detached from it for seismic design purposes. Facing panels are commonly large units, often covering the full width of a structural bay for a story height. Construction handling is a major determinant in sizing such panels - either must be limited (usually for ease of carriage), or because over large panels become impractical to Handle. The authors continued, when large heavy facing panels are used, provisions for seismic movement become critical.

This is usually achieved by having fixed bearing connections at the top of the panels and providing for lateral movement in detailing the bottom fixings. The inadequate provision of such bearings leads to cracking & crushing of the prefabricated concrete building elements & finally it may fail. As noted in (CPPCC, 2016) Wallace (1987) authored an article on a redesign using smaller precast concrete parts that improved constructability and enabled steel erection to proceed earlier. These smaller precast concrete parts were designed and detailed to participate in the lateral load resistance with the structural framing.

2.7.3 Early Planning and Decision-Making

One of the drawbacks to the implementation of prefabrication includes the late decision for its use. Final decisions have to be made early on in the planning process which means adequate attention is required; however, architects see this as a great challenge (Girmscheid and Kröcher, 2007).

In support of this early planning requirement as a constraint, (Wong& R. W. M., 2003) noted that tighter coordination is required for the structural design, planning, procurement and approval stages of construction.

Goodier and Gibb (2007) identified longer lead-in times as a significant setback, to contractors in particular, because the use of prefabrication could mean delay in on-site project commencement. One comment was that to minimize lead-in times meant that prefabrication needed to be integrated right from the beginning of design and a better coordination was required to reduce costs as well. This would require the integration and education on supply chain as well as design flexibility. Cooperation amongst professionals would be necessary at the earliest stages of the project in order to ensure proper integration of prefabrication into the building design; however as affirmed by the authors, cooperation amongst concrete prefabrication companies is complex and lacking. Process, according to (Blismas et al. 2005) is one of the main constraints of prefabrication. Clients and designers are unable to freeze the design and specification of the project at an early enough stage for the manufacturing process to commence concurrently with other works in order to achieve delivery when required.

Conversely, with traditional construction, clients and designers are free to make changes during the construction phase. It is noted that changes to the design of a project, regardless of the construction methods, affects its efficiency; however, these effects are more apparent in prefabrication. Therefore clients and designers must be forced to conclude all design processes early enough in order to benefit from prefabrication. The difficulty in modifying components once produced even upon the discovery of errors, meaning the need for rework, time delays and extra costs (Li et al., 2011).

2.7.4 Requirement of Heavy Equipment

Heavy machines and equipment are very crucial in the production and construction phases of the precast building components and require higher investments and specialized manpower for operation of equipment, transportation and installation purposes.

A) Production Equipment

Capital and technology employed for the initial investment is a very crucial factor. Plant, equipment and skilled workers must be obtained before they start production. Such huge investments may be used only if there is sufficient demand for the product. On the other hand, the production of the components may be carried out directly on the construction site, minimizing transportation.

B) Construction Equipment

Construction and installation of prefabricated parts and their location on their position requires
different equipment. In the case of construction of such a system it is important to incorporate
sufficient operating costs.

A typical device is a crane that is used in the construction of multi-story buildings and it has to be designed as suitable for handling and erecting purposes. Besides, the equipment of the transportation of precast concrete elements also needs, specialized and heavy equipment which requires high initial investment cost.

2.7.5 Greater working Spaces

Greater working space is the area requirement of factories or projects of prefabricated construction projects for inventory. Congested urban areas are difficult for storage and transportation of prefabricated components. Component inventories may be either inside the factory or outside the factory that is in construction sites.

In Hong Kong, practical constraints to the adoption of prefabrication were outlined by (Wong and R.W.W, 2003) to include the need for large workspaces to handle precast elements, where overcrowded urban environment, proved difficult; this congested state of the environment is the reason for the difficulty in access and delivery of heavy precast elements to the work site. In addition, where large numbers of precast components are structurally utilized, quality assurance becomes a critical issue and there are more demands for planning and management.

Li et al. (2011) report on the risk of accidents associated with the installation of heavy prefabricated components. Because the minimization of such risks through the introduction of new safety technologies is not yet given, they are simply avoided by employment of skilled workers and careful monitoring. Blismaset al. (2005) further suggest that a broader understanding of the constraints is required, arguing that although prefabrication can contribute to change in the industry, it itself depends on change in order to be widely adopted.

2.7.6 Transportation and Delivery

The cost savings achieved by prefabrication are usually partially offset by transportation costs from the factory to the project site, particularly where the prefabrication is produced off site of the construction processes. In addition, road transportation regulations in certain countries may also pose as a barrier to the transportation of heavy prefabricated panels and slabs. Huge panels and components are mostly not required in the transportation and handling of the precast construction, this is another drawback which needs the requirement of smaller dimensions and weight of the components, especially for longer distance transportation.

Such limitations ought to be given serious consideration prior to the adoption of prefabrication (Abdullah, 2007). As much as possible, elements should be delivered into position directly from the transportation. The usual process involves direct placement of the elements into the structure without turning or on-site storage.

Where on-site storage space is limited, considerations for offsite storage can be made; therefore additional incurred costs should be accounted for. However, site-stored elements are susceptible to damage and repetitive handling from site stacking. During transportation, the movement and vibration of components should lead to damaged and disintegrated parts, which in other words is the removal of components and wastages can occur. Hence, the weight and dimension of the components and the vibration of such components for traveling a longer distance, especially at the time (area) of high temperature should cause to shrinkage and cracking. Conversely, it causes to change in volume of the PC components and this problem can expand through the whole structure of the building& it may be considered as the major problem of precast components, particularly the shippement can across through longer distance.

2.7.7 Handling and Erection

The erection and assembly of precast components require heavy equipment such as cranes, especially in the case of high-rise buildings. These costs and operations need to be given consideration in the case of implementation of prefabrication (Abdullah, 2007) noted in (Edima, 2012). A specialist team generally carries out erection and assembly of precast components. The main operations are the offloading, handling, installation of the components, lining and leveling of the cladding elements, jointing and subsequent waterproofing of the whole structure. The on-site lifting equipment and attachments must be similar to those obtainable at the factory.

Where necessary specialized equipment have to be designed for conditions like lack of headroom or access to already erected components. In the event of on-site storage due to delay in delivery, appropriate still ages and racks are needed to prevent damage to the precast elements. It is paramount that personnel are assigned responsibility for the structural integrity of all fittings, connections and weather-tightness where cladding is involved. In short, names of persons responsible for all erection operations need to be published where quality assurance firms are employed.

2.7.8 Productivity Factors during Installation and Erection

Precast concrete products are generally used to shorten project duration and provide higher quality and more sustainable construction projects. There are many factors affecting productivity in precast concrete construction sites and there is a lack of research in terms of estimation tools for prediction of precast installation times for different components that are widely used in precast projects (walls, columns, beams, and slabs).

Some of the productivity factors of installation and erection processes are:

- ❖ Dimension and weight related factors of the components
- ❖ Crane and crew related factors
- ❖ Distance, location, elevation and shape related factors
- ❖ Rebar, Lifting, Lifting Inserts, Props And Prop Inserts Related Factors, etc.

2.8 Problem Assessment Techniques in Prefabricated concrete construction

An appraisal of building systems, their characteristics and the challenges they pose to the construction industry, especially in urban, fast-paced regions like the UAE and Africa, the use of prefabricated construction methods should be adopted and the problems of facing this technology should be identified for the achievements of their goals (Edima, *2012).*

2.8.1Standard problems in prefabricated component construction.

According to (Nihar et al), prefabricated construction is constrained by a lot of problems at the project level and at the factory level. By emphasizing the challenges faced, there is a needtoaddresstheconcernsfortheadoptionofprefabricatedtechnologyat the sector. As they noted, the problems weregroupedinto4categorizes as:

- Standardization, Procurement, and Technological aspects
- Documentation and Design aspects
- Skill Development and human resources
- End-user perspective (acceptability and social dimensioning).

According to their study, they identify the following common problems of prefabricated concrete components in building projects and rank them in order of their greater importance index.

Table2.4 Common problems in precast elements (Nihar et al)

No	Problems faced at project level	Category	RII
1	High Initial Investment in factory economies of scale	Standardization, Procurement ,and Technological aspects	0.84
2	Lack of Skilled Manpower	Skill Development and human resourc	0.81
3	The additional burden of taxes, Excise& VAT for investments	Standardization, Procurement Technological aspects	0.81
4	Connection and joint related problems(Leakage)issues	Acceptability and social Dimensions	0.81

5	Joint stability Issues during Erection	Standardization, Procurement ,and Technological aspects	0.80
6	Lack of Standardization	Standardization,Procurement,and Technological aspects	0.79
7	Design change related issues	Documentation and Design related	0.77
8	Requirement for huge equipment &stockyards material handling &storage	Standardization, Procurement,andTechnological aspects	0.76
9	Lack of expertise and technical know-how	Skill Development and humanresources	0.76
10	Complex design issues	Documentation and Design related	0.75
11	End user friendliness	End-user perspective	0.75
12	Scheduling-Lead Time& delivery cases	Standardization, Procurement,andTechnological aspect	0.73
13	Need for standard manuals ,schedule of rates	Documentation and Design related	0.73
14	Transportation for Long distances (locationrelated) problems	Standardization, Procurement,andTechnological aspects	0.72
15	Incorporation of MEP Services	Standardization, Procurement,andTechnological aspects	0.68
16	Inventory cost (Storage cost)	Standardization, Procurement,andTechnological aspects	0.67
17	Loading and Unloading related problems	Standardization, Procurement,andTechnological aspects	0.65
18	Construction Difficulty during rainy season	Standardization, Procurement,andTechnological aspects	0.48
19	Misalignment and non-overlapping problems project level	Standardization, Procurement,andTechnological aspects	0.44
20	Durability related problems for clients	Standardization, Procurement,andTechnological aspects	0.42
21	Supply and Demand cases between factory projects	Standardization, Procurement,andTechnological aspects	0.41
22	Material consumptions for construction	Acceptability and social Dimensions	0.39

23	Weak Seismic load and earth quake resistanc	Acceptability and social Dimensions	0.37
24	Creep and Cracking problems	Acceptability and social Dimensions	0.36
25	Poor quality	Acceptability and social Dimensions	0.34

As shown in table 2.4, it is mainly pointed out that the economies of scale ,high initial investment ,the additional burden of taxes and lack of skilled manpower is pushing prefabricated technology to be economically unviable option for adoption in the construction sector. According to their study, Standardization, Procurement, and Technological aspects are critical cause of the problems in the factory. To avoid such challenges, a brain storming session was conducted by inviting all the factory experts related to the adoption of precast technology, and amicable solutions are proposed by the industry. But in my study, these problems will be assessed in the desk study at the factory level and the major causes (categories) will be identified before a questionnaire is prepared and posed to the respondents.

2.8.2. Assessment of factors affecting productivity of precast installation

According to previous studies, the important processes in the erecting and installation processes of prefabricated construction are**:**

Preparation, inspection, and Lifting:

This is performed by a signal man (rigger man) at the storage area. The component is quickly checked against physical damages (if any) and then the signal man will attach the crane hook to the lifting inserts on the element.

Lifting:

This is the process of the crane raising the component to be installed at the unloading point.

Adjustment, fix, and unrigging:

The element will be adjusted and fixed at the designated location based on the drawings.

Crane return:

As the crane hook is detached from the lifting inserts, crane returns for the next cycle or other lifting purposes.

Based on such studies, about eighteen productivity factors that are crane productivity factors, preparation and fixing related factors were focused on site visits and observation during the installation stage of precast construction. Broadly speaking, such site visits, observations and measurements are the primary tools to determine the productivity factors of prefabricated concrete components during the installation stage.

Further, these detailed investigations are also important to classify component types in precast construction during transportation and inventory phases as noted by (Ali and Robert,2015).

Precast concrete elements were used to build a model to predict the erection time of different precast elements including structural or nonstructural walls, columns, beams, and slabs as he noted.

According to their study ,storage type (isolated or among others), length, and area for preparation activities; crane angular movement between installation and storage points, distance from the element to the crane at the storage area, orientation of the element (vertical or horizontal), type of the crane used (tower crane or crawler crane), elevation of the installation point, and weight for lifting time; weight, location type (exterior or interior), number of prop inserts to be used for props installation, and number of diagonal props for fixing activities are some determinant problems during the erection stage of prefabricated concrete components.

The following table shows, the general Characteristics of PC elements used to select the productivity factors of precast installation**.**

Table.2.5 Observations and measurements from the site (Ali and Robert, 2015).

	Wall	Column	Beam	Slab
No.of cases	126	80	34	73
Length(m)	1.40-5.75	0.40-2.00	5.57-9.22	2.40-8.73
Width(m)	0.10-0.25	0.20-0.75	0.30-0.80	0.37-2.40
Height(m)	2.80-3.58	2.80-5.80	0.32-0.60	0.07-0.27
Weight(t)	0.95-7.31	1.00-3.50	2.06-5.66	0.80-3.09

The table shows that different components were observed and measured to determine a variety of productivity factors at the installation stage of elements and the following productivity factors were identified and listed below in his study.

Name(Factor)	Description	Coding (Unit of measuremen
Weight(X_1)	Component weight	Ton(t)
Area(X_2)	Largest surface area of the component	Square meters(m^2)
Length (X_3)	Longest length of the element	Meter(m)
Height (X_4)	Component Height	Meter(m)
Storage Type (X_5)	The component is stored among others or being isolated	1:Isolated 2:AmongOthers
Storage to Crane(X_6)	Distance from component to crane cen in the storage	Meter(m)
Installation to Crane (X_7)	Distance from the installation point to crane center	Meter(m)
Crane Angle (X_8)	Angle between storage and installation	Degree
Crane Type (X_9)	Type of crane used	1:TowerCrane 2:CrawlerCrane

Installation Type(X_{10})	The component is installed among others isolated	1:Isolated 2:Amongothers
Location Type (X_{11})	The component is exterior or Interior	1: Exterior 2:Interior
Rebar(X_{12})	Number of rebar to fix the component(vertical elements)	Number:1…n
Lifting Inserts (X_{13})	Number of lifting inserts of the componen	Number:1…n
Props (X_{14})	Number of diagonal props for tempor support	Number:1…n
Prop Inserts (X_{15})	Number of holes to be drilled for pr installation	Number:1…n
Fix Crew Size (X_{16})	Crew size in charge of precast installation	Number:1…n
Elevation (X_{17})	Elevation of the installation point	Meter(m)
Shape (X_{18})	Component orientation(Vertical and Horizontal)	1: Vertical 2: Horizontal

These lists are the factors affecting precast erection productivity are the major problems particularly at the installation stage of prefabricated elements used in high rise building projects However, the shape of components, weight, and every dimension of the components are the basic factors that should be observed and measured not only in the multiple linear regression model but they are also very crucial in model development of the transportation and inventory problems, especially in the linear programming problems (Ali,2015).

2.8.3 Assessment of cost related problems in prefabricated concrete construction

2.8.3.1 Linear programming Models

Linear programming is a mathematical modeling technique designed to optimize the usage of limited resources. As mentioned by(Grit,2013) successful applications of linear programming exist in the areas of military ,engineering, industry, agriculture, transportation, economics, health systems, and even behavioral and social sciences. During production and construction of prefabricated components different cost categories can be analyzed including; the cost of the mold (initial production) cost, transportation cost, inventory (storage) cost, and installation cost and finally the objective is to minimize the overall such costs using optimization models such as ILOG CPLEX Optimization studio, LINGO,GAMS and or other mathematical modeling optimizers. But, in this topic only the transportation and storage cost of prefabricated concrete elements will be seen in detail.

Optimization is a usual tool for precast factory planning in previous production stage researches. Kuo et al, investigates various mathematical modeling of prefabricated components with more concern in storage and transportation stages.

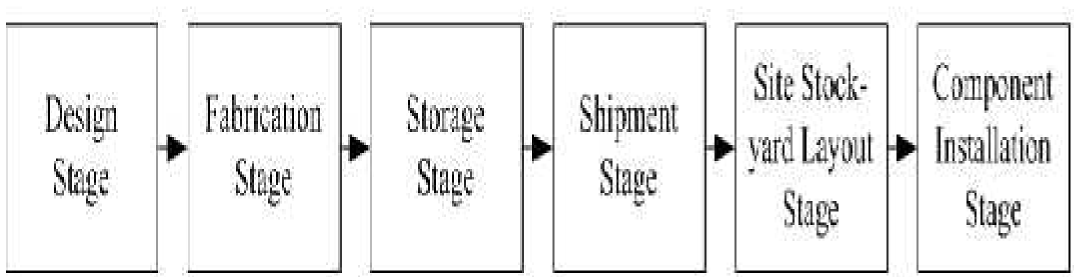

Fig.2.1 Phase of prefabricated components

Transportation Stage

As Kuo et al noted Transportation stage is ignored in previous precast management studies. Components always produced with few redundancies in a construction precast project, and all of them must be transported for installation to meet project requirement. Therefore, the cost of transportation can be treated as a fixed cost in most cases without detail delivery consideration because component delivery is necessary in a project. Thus, component transportation has been a parameter of fix cost which does not need to plan. However, the component transportation still plays an important role in factory business.

There are two kinds of transportation must be recognized in factory business: component movement within a site and component transportation between two sites for a long distance. Component movement within a site means that components are moved within the factory, a storage site, or the work site in short distance. Equipment such as cranes and trams can be utilized for such case. These equipment are owned or rented for daily business by precast factory. They also recognized that, transportation cost can be neglected from single precast project or transformed onto the cost for factory or site setting cost. The other, component transportation for a long distance is performed by trucks. In practice, trucks are mostly rented case by case when components transport in sites or turn over from any site to work site are sure. According to (Kuo et al, 2010), two important factors: weight of components and transported distance are commonly adopted for truck rental fee calculation.

Storage Stage

Storage stage had been considered in the component producing planning but simplified as an inventory calculation. Daily inventory is a vehicle variable between component producing and the demand. Produced components are stored in factory as inventory and this inventory add up all produced components in factory in a period (Kuo et al, 2009). In order to match the demand, the component inventory must equal to or exceed the demand of contract at the deadline of project.

Thus, a component producing plan considers daily inventory is able to create, and it is still practical for factory business mainly considering production stage. He also noted, the cost of inventory can be calculated through the quantity of stored components, and the inventory limits can be restrained if storage space is further concerned as constraints. Nevertheless, traditional precast factory can perform this kind of production planning formulation without considering how to store components. Component storage must be planed from perspective of a precast factory business. No matter how a precast factory closed to a manufacturing one, the nature of product of precast factory, construction component, is very unique to other industries.

Furthermore, according to (Kuo et al), there are several circumstances must be regarded in practical storage work: size of components; limitation in vertical loading of ground; safe distance between components and ways to store components. Briefly he also demonstrated that, the problem of component storage is a 2-dimensional or 3-dimensional spatial allocation with component identification. These considerations cause component storage complex and identification of component is necessary.

As Kuo et al noted (Chen, 2005) also mentioned that it is hard to ignore the storage cost to a precast factory business. A good storage plan is also benefit to help component delivering in right order and on time. In order to produce components smoothly and continually, Components which can be grouped into a same sharp, strength and material can be produced orderly by the same mold or grouped molds which belong to the same category certainly. Under this circumstance, components can be produced as soon as possible in production stage with minimal operation change of mold.

Foreign site storage that component is stored in a space out of both factory and work site is another issue in practical factory business. When the space of the precast factory is insufficient to store all components, foreign site storage is a common alternative.

Extra movements of components are needed to deliver components between different sites .Extending concepts of component zoning, adopted zones are located in sites, which are units of real storage space, to store components (Kuo et al, 2010). In practice, precast factories often have their own internal sites with movement equipment to store components conveniently. Adopted zones can be located in the factory. Locating zones determines which sites zone to store components. In other words, zones are grouped in sites to store components. The relationships between zones and sites concern storage space. Zones can be located in either internal sites or external sites.

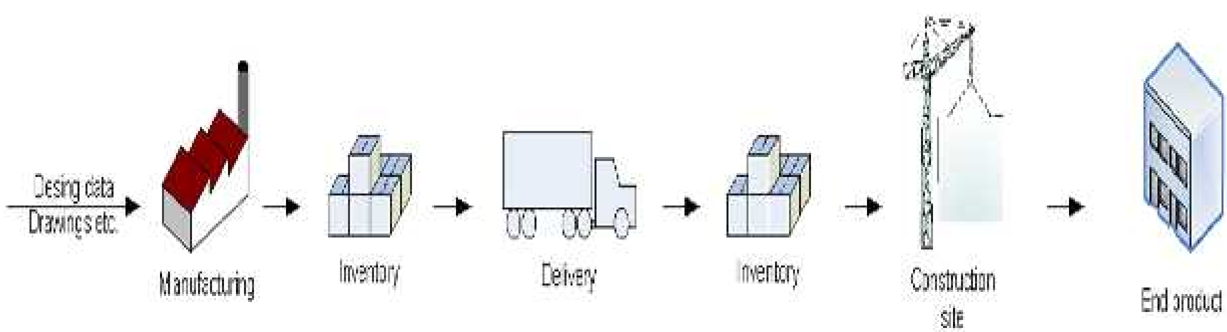

Fig.2.2 Supply chain for precast elements (jouni et al, 2013).

The above figure shows the different stage of precast elements, particularly, the storage and transportation stages. If zones are located in external sites, external sites have to be rented, and additional component transportation is needed. Moreover, components are produced and initially stored in the factory. Components of those zones in external sites are temporarily stored in zones in internal sites after component production, and then transported from the zones in internal sites to those zones in external sites. Buffer zones in external sites may be required to temporarily store components. The storage plan of a precast project can be represented as a problem of component zoning. Planners choose appropriate zones and arrange sites they own to store components.

2.8.3.2 Storage-Transportation Optimization Model

According to the practical situations and problems of component storage and transportation of the prefabrication factory, this study defines a mechanism of optimization model which employs the concept of basic zoning and minimization of total cost to conduct storage and transportation of prefabricated component (Kuo et al, 2010). This study suggests that the provision of an optimization mechanism for handling of component between the existing storage space of prefabrication factory and different storage space, provided that the supply and demand are known. As they demonstrated, the chart of the model is conceived as follows:

Objective functions：

Minimize Total Cost = IC + TC, Where, IC= $\sum_{i=1}^{np}(UPi * PCSi) + \sum_{i=1}^{ni}(UIi * ICSi)$

TC= $\sum_{i=1}^{ns}\sum_{j=1}^{ns}\sum_{k=1}^{ct}\sum_{l=1}^{p} TSQ * [TC1k + TC2k] + \sum_{i=1}^{ct}\sum_{j=1}^{p} Dij * TC3j$ - $\sum_{i=1}^{ns}\sum_{j=1}^{ns}\sum_{k=1}^{ct}\sum_{l=1}^{p} TSQ * TC3k$

Constraints Equations:

1)Judging the positions of zones: Storage zones to be located inside or outside the prefabrication factory.

$\forall i,\ M*UP_i \geq \sum_{j=1}^{ns} \sum_{k=1}^{p} SLP\ (j, i, k),\ i \in np$

$\forall i,\ M*UP_i \geq \sum_{j=1}^{ns} \sum_{k=1}^{p} SLI\ (j, i, k),\ i \in ni$

2) Zone allocation limit 1: Each zone cannot be located at more than two sites.

$$\forall\ i, j,\ \sum_{k=1}^{np} SLP(i, j, k) + \sum_{k=1}^{ni} SLI(i, j, k) \leq 1 \quad i \in ns,\ j \in p.$$

3) Zone allocation limitation 2: No movement should be made after zoning and positioning.

$\forall i, j, k,\quad SLP_{i, j, k} \geq SLP_{i, j, k-1},\ i \in ns,\ j \in np,\ k \in p$

$\forall i, j, k,\quad SLI_{i, j, k} \geq SLI_{i, j, k-1},\ i \in ns,\ j \in ni,\ k \in p$

4) Limit of area for use: Limit of area in each storage zone inside and outside the factory

$\forall i, j\ \ PA_i \geq \sum_{k=1}^{ns} SLP\ (k, i, j) * SAj\ ,i \in np,\ j \in p$

$\forall i, j\ \ IA_i \geq \sum_{k=1}^{ns} SLI\ (k, i, j) * SAj\ \ i \in ni\ ,\ j \in p$

5) Limit of acquisition of supplied component: Only when the zone is inside the prefabrication factory can the component be acquired via production.

$$\forall i, j, k \sum_{l=1}^{np} SLP(i, l, k) \geq SS_{i,j,k}\ i \in ns,\ j \in ct,\ \ k \in p$$

6) Inventory control upon termination: Upon termination of a project, the inventory of components is allowed to be left only when storage zone is inside the factory.

$$\forall i, j \sum_{k=1}^{np} M * SLP(i, l, p) \geq IS(i, j, p), i \in ns,\ j \in ct.$$

7) Quantity of supply to zones: Quantity of products to be supplied to different zones

$\forall$i ,j $\sum_{k=1}^{ns} SS(k,i,j)$ = $SC_{i,j}$,i$\in$ct, j$\in$p

8) Initial inventory of zone: Quantity of initial inventory in each zone

?*i, j IS* $_{i,j,0}$ Z *OIS* $_{i,j}$ *i*Č *ns, j* Č*ct*

9) Daily inventory: Quantity of components stored in each zone every day

$\forall$i ,j,k$IS_{i,j,k}$ =$IS_{i,j,k-1}$+$SS_{i,j,k-1}$+$\sum_{l=1}^{ns} TSQ(l,i,j,k) + \sum_{l=1}^{ns} TSQ(i,l,j,k)$ - TWQ $_{i\,j\,k}$ - $\sum_{l=1}^{ns} TSQ(j,i,l,k)$

-$TWQ_{i,j,k}$-TWQ $_{i\,j\,k}$i$\in$ ns, j$\in$ct, k$\in$ p.

10) Limit of zone storage: Limit of components stored in each zone

?$_{i,j,k}$*IS*$_{i,j,k}$ ≤ *MSQ* $_{i,k}$ *i*Č *ns, j* Č*ct, k* Č *p*

11)Initial inventory of jobsite: Quantity of components at the jobsite at the beginning of the plan

$\forall$*i*, *IW* $_{i,o}$= *OIW*$_i$,*i*$\in$*ct*

12) Daily inventory of jobsite: Quantity of components stored in jobsite

?*i, j* *IW*$_{i,j}$= *IW*$_{i,j-1}$+$\sum_{k=1}^{ns} TQW(i,j,k)$-$D_{i,j}$, *i*$\in$*ct*, *j*$\in$*p*

13)Limit of jobsite storage: Limit of components stored in jobsite.

$\forall$i, j $IW_{i,j}$ ≤MWQ_i , i$\in$ct ,k $\in$ p

14) Finally, **jobsite is not** allowed to have any inventory left.

$\forall$*iIW*$_{i,p}$ =0, *i*$\in$*ct*

15)Zone Transportation Limit 1: Transportation of components within jobsite is not allowed.

$\forall$*i, j,k*, *TSQ*$_{i,j,k}$= 0 , *i*$\in$*ns, j* $\in$*ct, k* $\in$*p*

16) Zone Transportation Limit 2: The storage zones outside the factory are not allowed to transport components to other zones.

$\forall$i, j $\sum_{k=1}^{np} SLP(i,k,j)$ *M $\geq \sum_{k=1}^{ns} \sum_{l=1}^{ct} TSQ(i,k,l,j)$ i$\in$*ns*,*j*$\in$p

17) Zone Transportation Limit 3: The storage zones inside the factory are not allowed to accept any components transported from zones.

$$\forall i, j \quad \sum_{k=1}^{ni} SLI(i,k,j) * M \geq \sum_{k=1}^{ns}\sum_{l=1}^{ct} TSQ(k,i,,l,j) , \quad i \in ns, j \in p$$

Table2.6. Symbols and variables of equations (Kuo et.al, 2009, 2010)

Symbol	Total Cost Description	Symbol	Total Cost Description
IC	Inventory cost	$D_{i,j}$	Quantity of required component i for jobsite on the j^{th} day
TC	Transportation cost	M	Value of extremely great positive intege
UP_i	Variable (0,1) for the use of area (i) storage inside factory	SA_i	Required storage area in zone i
UI_i	Variable (0,1) for the use of area (i) storage outside factory	PA_i	Limit of area of zone i inside the factory
$TSQ_{i,j,k,l}$	Quantity of components k transported fro zone i to zone j on the p^{th} day	IA_i	Limit of area of zone i outside the factory
$SLP_{i,j,k}$	Variable (0,1) for the use of area (i) storage inside factory in zone j on t kth day	period	Last day of planned period
$SLI_{i,j,k}$	Variable (0,1) for the use of area (i) storage outside factory in zone j on t kth day	$SC_{i,j}$	Quantity of components i produced the j^{th} day
$SS_{i,j,k}$	Quantity of components j acquired fro production zone to zone i on the k^{th} da	$OIS_{i,j}$	Quantity of components j stored in zone at the beginning of the plan
$IS_{i,j,k}$	Quantity of components j stored in zo i on the k^{th}day	$MSQ_{i,j}$	Limit of maximum quantity components j stored in zone i
$IW_{i,j}$	Quantity of components j stored jobsite on the i^{th} day	OIW_i	Quantity of components i stored jobsite at the beginning of the plan
$TWQ_{i,j,k}$	Quantity of components j transport from zone i to jobsite on the k^{th} day	MWQ_i	Limit of quantity of components i stor in jobsite
ICS i	Cost of zone i outside the factory	np	Area of storage zones inside the factory
$TC1_i$	Transportation cost of component i storage zones inside and outside t factory.	ni	Area of storage zones outside the factory
$TC2_i$	Transportation cost of component from storage zone outside the factory jobsite	ns	Area of zone
$TC3_i$	Transportation cost of component from storage zone inside the factory jobsite	ct	Quantity of types of components
PCS_i	Cost of zone i inside the factory	p	Planned number of days of a period

The optimization model developed by this equation belongs to a subject of integer programming (IP) so that it can be solved by the general mathematical programming tools (GAMS). Since the variable belongs to discrete-type variable, it can also be solved by constraint programming (CP) technique. Such types of general equations uses IBM ILOG CPLEX OPTIMIZATION STUDIO program to integrate the interface Model (Kuo et al, 2005).

2.9. Trends of precast construction in Ethiopia

Studies shows that there is no enough literature about the history & back ground of precast concrete components in Ethiopia, because of the reason that there is a gap for the knowledge &skills of precast concrete elements in building projects. But, for a country like Ethiopia, where timber &eucalyptus poles resources are limited, the application of using prefabricated concrete system of construction not only has economic benefits but also preserves the national resources by avoiding excessive use of formwork & scaffolding. The increasing price of building construction projects, primarily due to increasing prices of the building materials, and construction delaines, conversely, calls for in expensive & faster methods of construction. The use of such methods of construction, especially in a developing country like, Ethiopia where there is a limited source of building materials might be proved economical .One of such cheaper & faster method of construction is the use of prefabricated concrete components.

Generally, the application of precast concrete elements for slabs, columns & Girder beams in Ethiopia has been limited in smaller extent since its inception and concerning different problems in the usage and cultural implication of using precast concrete elements in the Country.

2.10 Gap Analysis

The purpose of this study suggests the awareness of the problems of prefabricated concrete components in the construction industry of Ethiopia by achieving the objectives of the study. It also helps to identify the reliable construction methods in construction projects in the country.

Prefabricated concrete buildings play a remarkable benefits and cost savings during production of components and construction of projects. Moreover, the requirement of shortly constructed buildings for dwellings and other commercial purposes should be essential for countries like Ethiopia. But, such types of prefabricated buildings should not be carefully studied to successfully achieve the requirements of these buildings in our country. As discussed broadly in the aforementioned topics, different countries revealed the benefits and problems of prefabricated concrete components in broader context, but in Ethiopia such types of benefits and problems haven't yet studied in detail even if it is very critical.

Generally speaking, problem assessment techniques did not observed and assessed carefully in Ethiopia which indirectly initiates the applicability of the elements in construction industries, particularly in high rise buildings. Farther, the assessment of such problems and benefits in the country plays a greater role for the advancements of utilization and application of such construction methods. The greater gap of using such technology in Ethiopia is because of the shortage of different studies and knowledge in the country. In contrast to other countries, Ethiopian construction industry hardly evaluated those problems in the country and tried to solve for the wider application of the prefabricated construction methods. Broadly, techniques of problems identification (assessment of problems) of precast elements were not observed in detail in Ethiopian Production Company and in their projects.

The productivity factors at installation stage of concrete components also needs further studies to analyze their impact on the erection phase of the components that has wider influence on the installation activity of the prefabricated concrete elements through time delaines beyond the actual planned time of the erection of components in projects. Even if every activities seems to have smaller minutes or hours to be delayed beyond the expected time of the installation activity ,the overall time of each activity sums up of an extra construction cost of the factory.

Analogously, the assessment of cost related standards of prefabricated components of their storage and transportation cost was not given greater emphasis in the local practice, but a careful study of such cost parameters should be given priority in international standards beyond the production and construction of such components. Generally, the costs are not only on the storage and transportation cost, but also the initial investment cost & erection costs including the cost of molds and other additional cost parameters and such costs are resolved by different optimization models in order to minimize the actual cost of production and construction of the components.

However, these important concepts of cost related problems were not emphasized in detail in Ethiopia for further advancements of prefabricated construction.

CHAPTER THREE: METHODOLOGY OF THE STUDY

3.1 General

The main objective of this topic is to view the assessment of the problems in prefabricated concrete elements in Ethiopian building projects. The study included both quantitative and qualitative methods with inductive approach. Thus, it was a mixed type research which adopted both qualitative and quantitative method of research writing. It should be noted that a mixed approach of quantitative and qualitative is possible (Kumar, 1999). Bazeley (2004) states that mixed method of research writing has regained not just acceptability, but popularity, with a significant number of studies arguing its virtues in terms of greater understanding and validation of results as noted by (Getaneh,2011). Working with mixed methods raises a range of issues beyond those encountered within a particular methodology. Bryman (2006) also states that research that involves the integration of quantitative and qualitative research has become increasingly common in recent years.

Quantitative methods: are methods that involve with numbers and quantities like measurements, tests &surveys which are likely to be unstructured and allow for aggregation and generalization and needs more time for the study.

Qualitative methods: are method that involves with qualities and words. These methods are more open and provide for depth explanations to the study and these methods are structured interviews, observations and questionnaires and these methods of the study requires the respondents to explore the topic in different perspectives which is more descriptive approach.

Deductive Approach: Deductive approach for the research move from general ideas or theories to specific or particular ideas and situations: the particular theory is deduced from the general. It is a theory based to prove or disprove the already existing knowledge or problem.

Inductive Approach: moves from particular situations or ideas to make or infer broad or general ideas or theories. It is a problem initiated for theory or knowledge contribution of the society.

Therefore, a significant approach of the study for the reliable results and for the intended objective of the study will be deductive approach & an integrated method of research writing.

This is because of the fact that time constraints and the nature of the problems encountered in the study. The sampling technique that was conducted was simple random sampling. In simple random sampling, each elementary unit has an equal chance of being selected in the population &is free from sampling bias.

3.2 Research strategy and Target areas

The methodology followed for the thesis was both qualitative and quantitative methods with deductive approach, since problems that were identified and assessed was a nature of both qualitative and quantitative. In addition, the sampling technique was simple random sampling to avoid bias and to ensure reliable information. The primary data was mainly focused in selected professionals and skilled man power in different projects of Ethiopian Building Technology and Construction Sector, ECWC such as:

Production & Construction Department in BTCS (desk study)
Information and communication Technology incubation center (ICTIC)
Addis Ababa Melese Zenawi Leader Ship Academy (AAMZLA)
Kotebe Metropolitan University Administration Office (KMUAO)
Ethiopian Revenue and Custom Authority (ERCA) and other construction projects constructed by the company through questionnaires and measurements.

The data that was collected from such projects of (BTCS) was a dual purpose which was considered as both the construction and Production Company of the components. Here, the data was collected from completed projects and progressed projects. There were eighteen projects for the questionnaires survey. Four projects mentioned above were currently progressed whereas the rest fourteen projects were completed projects. But, in addition to responding to each questionnaire, the direct involvement of each respondent in the construction of completed project were carefully checked during the desk study.

3.3 Sources of Primary Data.

The sources of primary data that was conducted were mainly desk study, questionnaire survey and site observation & measurement.

3.3.1 Desk study

A desk study of the constraints of prefabricated concrete parts in building projects of Addis Ababa was taken into consideration in Ethiopian Building Technology and Construction Sector (BTCS). The main participants in the desk study were some of the professionals of design Engineers, architects, skilled manpower, estimators and office engineers particularly at office. The method mainly focused on production and construction departments at office level, excluding site engineers and erectors to seek preliminary information about the major problems in the company. The desk study was conducted as a supplement of the questionnaire and measurements in order to find the relevant information to the study. In the desk study, additional problems on precast projects, the back ground of each respondents and completed projects by the company and their status was identified. Here, the respondents of completed projects were carefully identified and selected for the questionnaire survey. In this regard, respondents of the questionnaires must be directly involved during the construction of sample projects.

3.3.2 Questionnaire survey & measurements

The questionnaire survey was developed based on the findings from the literature review and distributed to the target areas of (BTCS) and to the client organizations to supplement the desk study. From such samples, the population as sources of primary data was categorized as production department and construction department. But, data from the production department was considered for both the desk study and the survey. The source of data from the construction department was including18 projects like, ICTIC, AAMZLA, KMUAO, ERCA, that were currently in progress, but there was limited projects constructed during the year ,in this regard data was also collected from completed projects by document review of the company. In eighteen projects, data was collected from both the contractor (BTCS) and the clients mentioned above.

Likewise, measurement was also the primary data collection method for the study in addition to the desk study and the questionnaire survey. This process was involving the actual measurement of precast elements and measuring their dimensions & recording all the productivity factors that face at the installation phase of precast construction in selected projects. Here, the main focuses were dimensions or sizes of the components and weight of components that are productivity factors at the erection stage. Hence, all the productivity factors were measured and observed to those currently progressed projects in order to choose the most problematic components as mentioned in the literature. During site observation and measurement, additional information was also gained and recorded from the erectors and site engineers at projects.

3.3 Variables and preparation of Questionnaire

The ways of data collection was conducted as posing the prepared questionnaire to the responsible respondents for the designed samples. Thus qualitative, where a more structured questionnaire was prepared. The questionnaire contained closed ended type questionnaires that were easily answered by the respondents. The questionnaire was prepared based on the concerns of the respondents. It was mainly focused for site engineers in BTCS, project managers, machine operators, supervisors and erectors.

The first part of the questionnaire includes personal information, profession, and responsibilities. The second part contains thirty-two closed ended type questionnaire in tabular form (very high, high, intermediate, low& very low).The basic questions and variables developed were that of the major problems mentioned in the review, like transportation, handling &storage related factors, connection related factors, Design inflexibility, specialized manpower& equipment related factors, and initial capital cost related factors. Lastly, the case of transportation and storage related factors was developed as a case study independently for selected projects of Goro, Ayat and Kotebe and the required data were obtained from the factory. This projects were selected for the case study, because of the progress of the project.

3.4 Design of sample and respondents size

The populations in the target areas that are precast buildings constructed by BTCS which are currently constructed by the company were about 48 buildings in Addis Ababa. But, by considering the precision as **e**=0.099885, the total project sample were designed as 32 using the formula, $n=N/N+N\mathbf{e}^2$.However, only eighteen projects were considered for the study, because of the fact that the involvements of respondents during the construction of completed projects were a mandatory for selection of the questionnaire survey. The total number of sources of data required was focused on eighteen projects through questionnaire method. Here, fourteen sample projects were completed whereas the rest four projects were in progress. Beside document review, respondents were carefully selected who actually involved during the construction of completed projects.

The required number of respondents for selected projects for the study was from construction department and supervisors of clients. The respondents of the data were professionals and skilled manpower and these respondents were selected according to the progress of the project and their professional and technical capability. Generally, most of the respondents were erectors, supervisors and site engineers and about 55 respondents were selected randomly and distributed to the target projects ,but only 42 of them was successfully filled by the respondents .Hence, all data sources were analyzed and interpreted because of the reason that there was limited projects for data collection.

3.5 Tools and Models Used in the Study.

The tool (software) that was used in the study were that of the optimization model which is called GAMS Software which is used to analyze optimum cost of storage and transportation in the construction of prefabricated concrete components in the study. Therefore, after developing the model for transportation and storage stage of the three projects, this software is used for analysis of cost of transportation and inventory for each components in each projects.

The model can solve any of constraints equations, particularly programming which require General Algebra Modeling System. It is successfully used to solve complex scheduling problems in sectors such as manufacturing, aircraft assembly, computer and network scheduling, space (earth observation), autonomous systems (assistant robots), civil engineering, transportation, port management and manpower scheduling.

3.6Method of Data Analysis

The analysis for this thesis was made based on the preliminary information collected through the desk study, questionnaire survey and measurement. The obtained data was analyzed and interpreted through discussion found from the results. This process mostly, used tables, percentages, Bar chart and mathematical approaches and models or software used particularly for cost related factors. In this case, the relative importance index (RII) of each problem was calculated and ranked according to their (RII). Moreover, storage and transportation cost obtained from the company in the case of (Goro, Ayat and Kotebe) projects was compared with the optimum cost that was calculated using Software. Finally, conclusions were made and recommendations were forwarded according to the findings of the analysis and discussions made.

CHAPTER FOUR: DATA ANALYSIS

4.1Introduction

In order to investigate the problems of prefabricated components in Addis Ababa high rise building projects, the survey was developed based on previous studies. However, the survey was developed basically not only on such studies but it also considered on the current trends and local practices of the country. Moreover, a desk study was conducted at the factory and on projects to overview the local problems in the prefabricated concrete components production, transportation, and storage as well as installation phases in order to develop the survey of the study. So, the survey is developed based on the desk study and on the suggested problems in the review .This part of the finding was analyzed in section one with emphasis given to the identification and impact of general problems on projects using the lickert scale method.

Section One

Generally, the survey of the study was focused on prioritizing the critical problems or ranking the problems according to the severity of problems found by the lickert scale which is termed to be the (RII-relative importance index). Relative importance index is a numerical analysis of the depth of impacts of each problem which was observed in construction of prefabricated buildings.

Hence, the RII is given by using the formula: RII = $\sum W / A \times N$, where

W = $w_i * r_i$; Where: i = response category index

w_i = weight assigned to i^{th} response = 1, 2, 3, 4, 5,

r_i = i^{th} frequency of total response for each factor

A = highest weight = 5

N = total number of respondents **[42]**

Generally, we have

$$W = w_1 r_1 + w_2 r_2 + w_3 r_3 + w_4 r_4 + w_5 r_5$$

$$RII = \frac{w_1 r_1 + w_2 r_2 + w_3 r_3 + w_4 r_4 + w_5 r_5}{5[r_1 + r_2 + r_3 + r_4 + r_5]}$$

The weights are given according to ordinal measurement scales in descending order. Ordinal scales are integer numerical values given in ascending or descending order for each response rates of the survey. The next table shows the value of each response rate during data analysis.

Table4.1.Numbers assigned to each response rate.

Responses	Weights	Frequency of respondents
Very high(w_1)	5	r_1-Number of response of **very high**
High(w_2)	4	r_2-Number of response of **high**
Intermediate(w_3)	3	r_3-Number of response of **intermediate**
Low(w_4)	2	r_4-Number of response of **Low**
Very low(w_5)	1	r_5-Number of response of **Very Low**
Total number of respondents(**N**) = $r_1 + r_2 + r_3 + r_4 + r_5 = 42$		

Finally, the problems of prefabricated elements were ranked according to the RII values calculated by the above formula and a detail comparison of the local and international practices were interpreted .The transportation and storage problems are farther evaluated in section Two.

Section Two

The case of transportation and storage costs were analyzed in detail to evaluate the cost related problems of prefabricated concrete elements during the phase of transportation and storage. To conduct these processes, the dimensions of every component were measured to determine the productivity factors at the installation stages in selected three projects (Goro, Ayat and Kotebe -Metropolitan University) and selecting those components having heavier weights, longer dimensions, common elements in three sites and large in quantity. The productivity factors are those factors faced at the erection stage, because of the fact that such building parts produced in the factory are very problematic in their erection stage and are expected to be greater impact in their transportation, storage and installation costs with loading and unloading related problems.

I. Measurements: Measurements and observations of prefabricated components were taken in the case of three projects as shown in Appendix 1**(**Table.**1b**) in bold**.**

The components were selected to assess the cost of transportation and storage due to their heavier weights, longer dimensions that are common to the three sites of (Goro, Ayat and Kotebe).Finally, the following components were selected which is very problematic based on the literature:

1. Slabs of size (4.2*4.2*.22) with weight 3200 kg and 1.28m^3 designed volume.
2. Cantilevers of size (4.2*1.28*.22) with weight 1425 kg and 0.57 m^3 designed volume.
3. Columns of size (0.34*0.34*5.79) with weight 2500 kg and 0.67m^3 designed volume.
4. Girder beams of size (4.2*1.2*.22) with weight2888 kg and 0.115 m^3 designed volume.

These components have found greater cost impact and problematic on the basis of transportation and storage processes as noted in the review. Besides, the unit cost standards of transportation and storage were taken from the factory to quantify the overall requirements of each component in each site and to estimate the optimum transportation and storage costs for a single trip of the truck or lovid. Generally, the total transportation and storage cost was also analyzed using data obtained by the model and finally a comparative analysis between the actual transportation and the obtained data were conducted. The transportation and storage optimization model for component transportation and storage cost analysis was calculated based on the following chart:

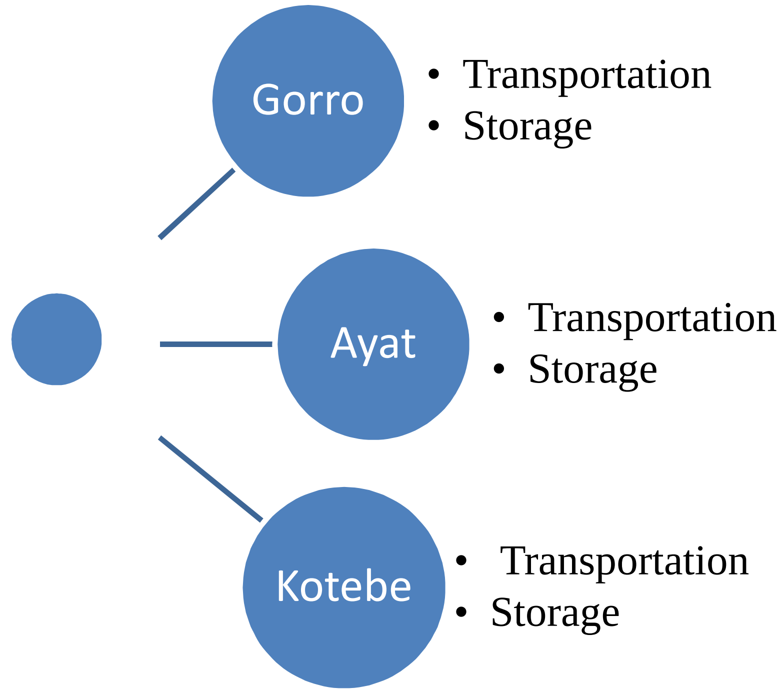

Fig 4.1.The chart of transportation and storage model in each site.

The objective function and constraint equations are given below

Objective Function:

$$\text{Min Z} = \sum_{i=1}^{3}\sum_{j=1}^{4}\sum_{k=1}^{2} C(i,\ j,k) * X(i,\ j,k)$$

Where, X (i,j,k) is the quantity of components to be transported or stored in each sites ,C (i,j,k) is the unit cost of transportation or storage cost in each site taken from the factory and is specific for specific site and component type.

i-is an index representing the sites (i=1, 2, 3).

Here, 1-represens Goro site,

2-represents Ayat site and

3-represents Kotebe site.

j-is representing the components to be transported or stored (j=1, 2, 3, 4).

1-is the slab elements

2-is the cantilever elements

3-is the column elements

4-is the Girder beams

Moreover, k- is an index of transportation or storage cost (k=1, 2)

1-is transportation cost

2-is storage cost

The constraint equations also verified as:

Slabs:

$$\sum_{i=1}^{3} \sum_{k=1}^{2} X(i,1,k) = 624$$

2. Cantilevers:

$$\sum_{i=1}^{3} \sum_{k=1}^{2} X(i,2,k) = 298$$

3. Columns:

$$\sum_{i=1}^{3} \sum_{k=1}^{2} X(i,3,k) = 449$$

4. Girder Beams:

$$\sum_{i=1}^{3} \sum_{k=1}^{2} X(i,4,k) = 186$$

Here, $X(i, j, k)$ the quantity of each component to be transported or stored in each of the required projects. And i-represents the projects or sites where k denotes either the transportation or storage parameter of components. Moreover, for k=1 in the above equations, it shows that the constraint equations of the transportation problem and for k=2, it indicates that the problem is a storage constraint of the components. Further, the coefficients of the objective function (transportation and storage unit costs), total production of each components in the factory and the variables and final equations are given in Appendix 1(Section Two).

Since, each components to be transported are also stored in the site, both the transportation and storage constraint equations represent the same equation but different in unit cost. The formulation of the transportation and storage problems in this analysis were containing about 25-decision variables and 8-constraint equations. Here, the objective function was to minimize the total transportation and storage cost of components in each of the three projects (Ayat, Goro and Kotebe) sites. Moreover, the transportation and storage cost of three projects were analyzed and the obtained data were also evaluated with the transportation and storage cost of the company for a single trip. Components transportation may be either using lovid or truck. The trucks are always rental in the company, but a lovid is non rental unless the company needs more than one lovid for a single trip.

Finally, a total transportation and storage cost of the factory were formulated and analyzed using GAMS software. The result found by the model were compared and evaluated in detail with the factories current storage and transportation costs in each projects.

4.2 Analysis and Discussion of Questionnaire Survey

4.2.1. Profiles of sample projects

The following table represents the number of sample projects in which questionnaires were distributed to respondents for the purpose of data collection in order to ensure the objective of the study.

Table4.2. Back ground of buildings in the study

Proje	Story Buildings	No Projects	Distributed Questionnaires	collected Questionnaires	Total Questionnair used in the study
1.	G+0	1	3	2	2
2.	G+2	2	8	7	7
3.	G+3	2	7	7	7
4.	G+4	4	6	5	5
5.	G+5	4	7	6	6
6.	G+6	1	4	3	3
7.	G+B+7	1	8	6	6
8.	G+8	1	4	2	2
9.	G+9	1	4	2	2
10.	G+12	1	4	2	2
Total		18	55	42	42

According to table 4.2, the questionnaire survey was conducted in eighteen different projects for the real analysis and investigation of problems identification on prefabricated concrete components in high rise buildings. The projects used in the study were all projects with G+0 and above, this is because, there is limited number of projects of precast construction in Addis Ababa that are currently progressed. In this case, 55 questionnaires were distributed in each project and 42 of them were successfully collected whereas the remaining 13 questionnaire survey were lost in different projects as shown from the above table and were not used in the data analysis and interpretation of this study.

4.2.2 Respondents Profiles

Table4.3.Number of respondents who successfully respond to the questionnaire.

Respondents	Designed	Successfully filling the questionnaire
Total	55	42

Here, as shown in table 4.3, 55 respondents were designed to be used in the analysis of this study, but only forty-two were successfully filled and returned the questionnaire in the study. So, in the analysis of the study about forty-two respondents were critically used in order to assess the problems of prefabricated concrete components in projects.

4.2.2.1 Educational back ground of respondents

The following table, show that the respondent's qualification and back ground in problem identification of study.

Table4.4 Respondents Background

Educational back ground	No respondents	Percentage composition (%)
Project Manager	2	4.76
Site Engineer	11	26.19
Supervisor	11	26.19
Office Engineer	1	2.38
Foreman	1	2.38
Erector	12	28.57
Machine operator	4	9.52
Total	42	100

The figure below is developed based on the above table. It shows the back grounds or professions of every respondents in the target areas during data collection.

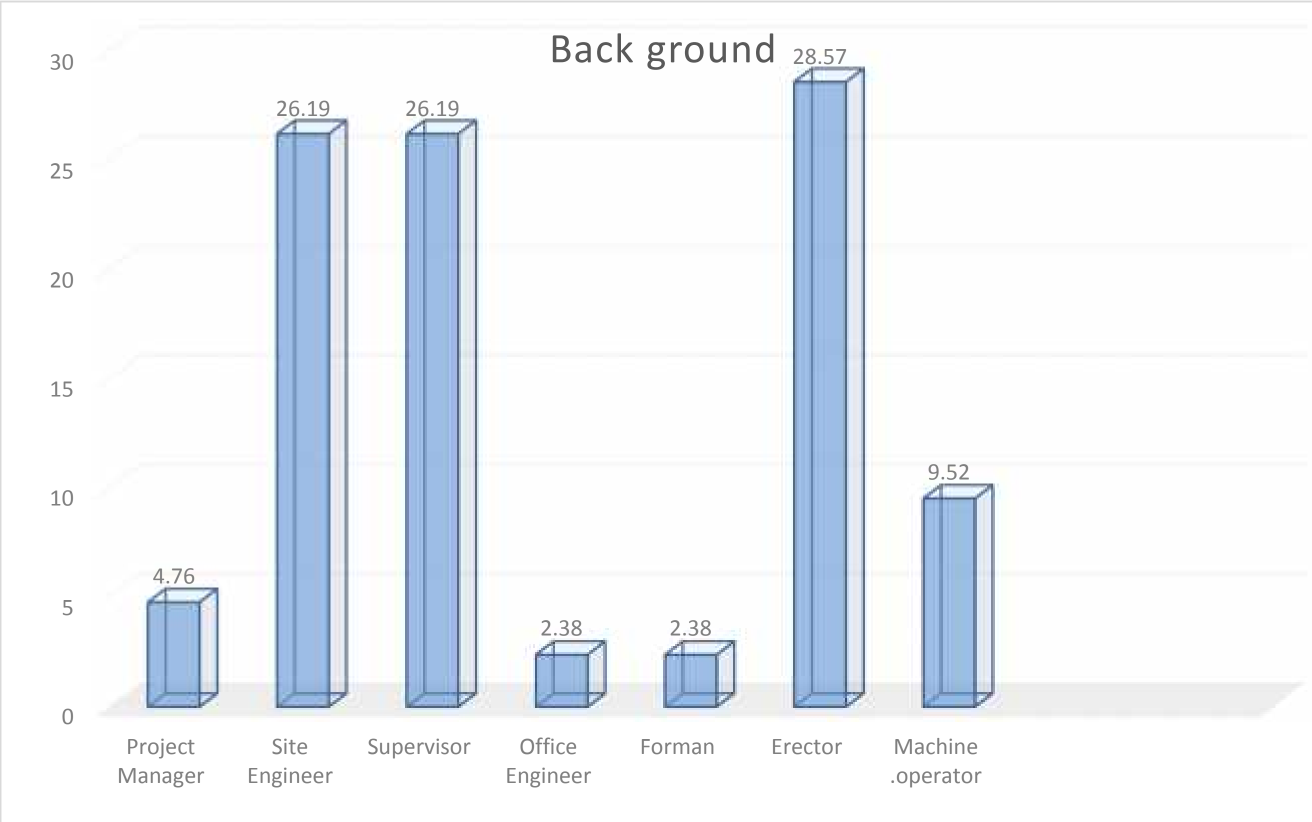

Fig 4.2 The figure represents the professions or back grounds of respondents that were involved in the questionnaire survey of the study.

From figure 4.2, we illustrated that about 4.76% of the total response indicate that of project managers, 26.19 % also showed that of site Engineers and supervisors each in the questionnaire of the study. Similarly, office engineers and foremen represent 2.38% each for the survey of the study. Generally, the study includes with 28.57% of erectors and 9.52% of machine operators for questionnaire survey regarding on the preliminary problem identification of the study. Here, most of the respondents were erectors, site engineers and supervisors as shown from figure that were frequently involved in the projects of prefabricated construction and are expected to provide an adequate information for the study.

4.2.2.2 Experience of the respondents in their company

The table below represents the experience of each respondents during questionnaire survey.

Table 4.5. Exprience of respondents.

Year of service for respondents	Number	Percentage (%)
1-5	19	45
6-10	3	7
11-15	2	5
15 and above	18	43

The following pie chart shows that the experience of each respondent in selected sample projects of the survey. Hence, from this figure the respondents' service is clearly indicated and shown. Therefore, 45% of the respondents have an experience of 1-5 years in precast construction, 43% of the respondents have an experience of more than 15 years and about 7% have 6-10 years of service in prefabricated construction whereas the rest 5% of the respondents have an experience of about 11-15 years.

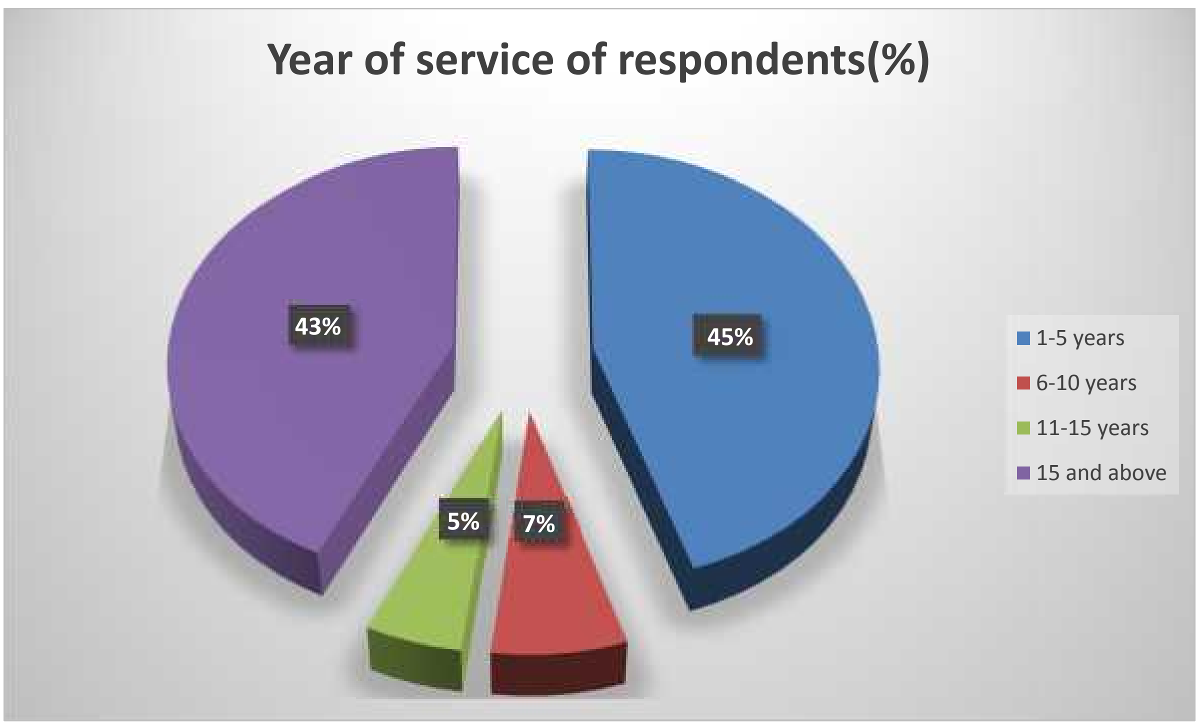

Fig.4.3 **Experience of respondents in prefabrication construction**

From the chart given above, we can conclude that most of the required respondents have enough experience on prefabricated concrete elements in different projects and are expected to provide a valid information on the assessment of problems of precast construction in building projects .Moreover, most of the respondents have an experience of more than 15 years in prefabrication of concrete elements and on construction of such prefabricated concrete components in projects. Generally speaking, data from completed projects were collected through these respondents and were carefully treated during this period for gathering of the required data.

4.2.3 Assessment of major problems in prefabricated concrete components used in Addis Ababa building projects.

The following points show that the assessments of problems and constraints of prefabricated concrete components used in Addis Ababa building projects. These problems were assessed mostly at project level where the construction of prefabricated concrete elements was conducted, particularly in eighteen projects. The identification of the constraints was also conducted at factory level to generalize their problems in the construction industry. In the study of problems in prefabricated concrete components in Addis Ababa building projects and at factory level, about thirty-two problems were identified. These problems were critically observed and illustrated in different journals and studies concerning on the topic. The identification purpose is to rank the major problems in their degree of impact both at the projects and at the factory and their impact is carefully measured and compared with the international standards found in the literature review. As discussed earlier, the Lickert Scale method to solve their relative importance index (RII) was a precise measuring tools during the analysis of the problems.

Using, $RII = \frac{w_1r_1+w_2r_2+w_3r_3+w_4r_4+w_5r_5}{5[r1+r_2+r_3+r_4+r_5]}$ as mention in the introduction part of the analysis.

The following table shows the basic problems found during data analysis. Here about thirty-two problems were found and ranked below that are collected in eighteen projects.

Table 4.6 The major problems found in the study

No	**Problem Descriptions at projects**	**Category (Generalizations)**	RII
1	Higher Initial Investment at factory level	Standardization, Procurement,andTechnological aspects	0.86
2	Transportation cost and time	Standardization, Procurement,andTechnological aspects	0.81
3	The requirement of huge equipment and machinery	Standardization, Procurement,andTechnological aspects	0.79
4	Lack of Standardization and limited standards mold	Documentation and Design cases	0.78
5	Lack of expertise and technical knowledge	Skill Development and human resource	0.76
6	Higher Maintenance cost for equipment and molds	Standardization, Procurement,andTechnological aspects	0.75
7	The need for standard manuals, schedule of rates a Documents.	Documentation and Design cases	0.74
8	Lack of Skilled Manpower	Skill Development and human resource	0.73
9	Supply and Demand related problems betwe factory and projects	Standardization, Procurement,andTechnological aspects	0.71
10	Inventory (Storage) cost related problems	Standardization, Procurement,andTechnological aspects	0.67
11	Complex design issues	Documentation and Design related	0.64
12	Design change related problems	Documentation and Design related	0.64
13	The requirement of greater working space in Urb areas	Standardization, Procurement,andTechnological aspects	0.63
14	The requirement of extra cost of admixture	Standardization, Procurement,andTechnological aspects	0.63
15	Aesthetic related problems for clients	Acceptability and social dimensioning	0.59
16	Loading and un loading related problems during transportation	Standardization, Procurement,andTechnological aspects	0.58

17	Installation and erection related problems durin construction	Standardization, Procurement,andTechnological aspects	0.57
18	Handling related problems in Building projects.	Standardization, Procurement,andTechnological aspects	0.56
19	The difficulty of de-molding and striping during curing	Standardization, Procurement,andTechnological aspects	0.56
20	Scheduling-LeadTime&delivery cases	Standardization, Procurement,andTechnological aspects	0.53
21	Connection and joint related problems(Leakage)	Acceptability and social dimensioning	0.50
22	Material consumption related problems	Standardization, Procurement,andTechnological aspects	0.49
23	Misalignment and non-overlapping problems of components at projects	Acceptability and social Dimensions	0.47
24	Construction Difficulty during rainy season compared to conventional construction	Standardization, Procurement,andTechnological aspects	0.45
25	Frequent occurrence of accidents on workers due its size and weight in high rise building projects	Standardization, Procurement,andTechnological aspects	0.44
26	Durability related problems for clients	Acceptability and social Dimensions	0.43
27	Low resistance to earth quakes and seismic load	Acceptability and social Dimensions	0.42
28	Boring related problems on workers as compared conventional construction	Skill Development and Human resources	0.41
29	Creep related problems after construction	Acceptability and social Dimensions	0.40
30	Shrinkage and cracking related problems	Acceptability and social Dimensions	0.35
31	Poor quality compared to conventional constructior	Acceptability and social Dimensions	0.33
32	Dumpiness and buckling related problems aft construction	Acceptability and social Dimensions	0.32

The above points are the factors found in the study from eighteen projects by questionnaire survey and the major problems are identified and interpreted in the following points .Moreover, the study focuses on those problems with RII greater than 0.67 as a major problems. Besides, the discussion also address on the local and international status of these problems and a conclusion is made and it also identifies those problems with least impact based on the above analysis.

4.2.3.1Discussionof top ten critical problems from the result.

According to the result found from the study in (Table4.6), the following sequential ranks were given for the first ten critical problems in the assessment of problems of concrete components in Addis Ababa high rise building projects. So, these problems are arranged in order of decreasing in their relative importance index (RII) to indicate the severity of each problem in different projects and factories of the components of concrete elements. In this case, the problems with severity index greater than or equal to (RII=0.67) were chosen as the first ten major problems in the construction and production processes of prefabricated concrete elements as shown below.

1. Higher Initial Investment at factory level (RII=0.86)

2. Transportation cost and time (RII=0.81)

3. The requirement of huge equipment and machinery (RII=0.79)

4. Lack of Standardization and limited standards of mold (RII=0.78)

5. Lack of expertise and technical knowledge (RII=0.76)

6. Higher Maintenance cost for equipment's and molds (RII=0.75)

7. The need for standard manuals, schedule of rates and Documents (RII =0.74)

8. Lack of Skilled Manpower (RII =0.73)

9. Supply and Demand related problems between factory and projects (RII =0.71)

10. Inventory (Storage) cost related problems (RII =0.67).

The following figure shows the top ten problems of prefabricated construction found in 18-projects

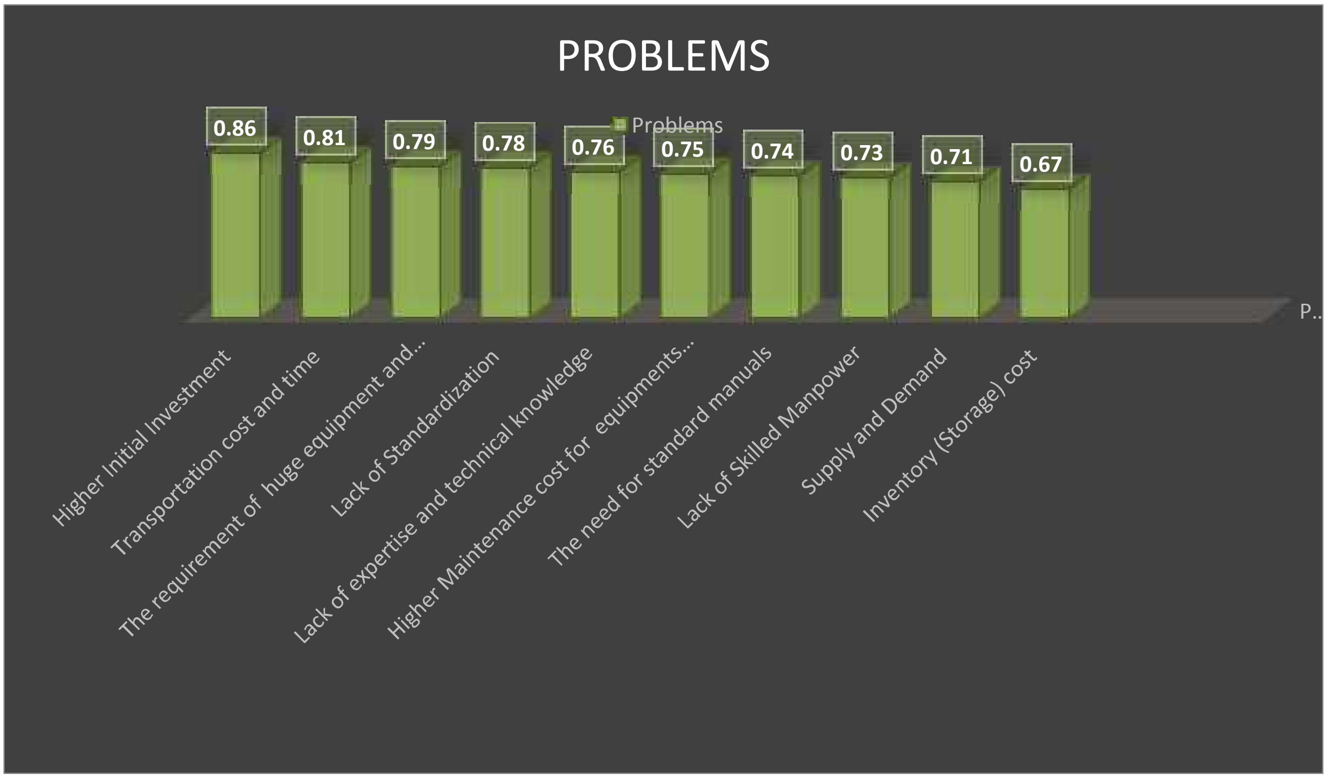

Fig.4.4 The first ten major problems

Based on figure 4.4, the following problems are ranked with their degree of relative importance index in projects and an in depth interpretation was made.

1. Higher Initial Investment at factory level (RII=0.86)

In this study, it is found that higher initial investment cost in the development of factories or industries is the most problematic cause in the construction and fabrication of precast concrete parts in high rise building projects. The severity index of this problem is about 0.86 showing that the most underlined parameter in the construction and fabrication development of prefabricated components in Addis Ababa building projects. In this case, the cost of heavy equipment's and machines, the cost of different standards of molds and any other initial requirements are the most considerable points during the investment stage of prefabricated concrete component production and lead to greatest problem compared to other assessed factors. Generally, in prefabricated concrete elements, the initial investment costs are the most problematic factor in the study. So, according to the category of sources of problems, standardization, procurement and technology aspects cause's greater impacts through investment cost related factors.

2. Transportation cost and time (RII=0.81)

From table 4.6, it is shown that greater requirement of transportation cost and time for longer distance is also found in the second category of greater impacts during production and construction of components of building projects. From the result, it is found that relative importance index of (RII=0.81) indicates that the severity of transportation cost and time taken for longer distance shipment of components between the prefabricated concrete factories and construction projects. However, transportation related factors were investigated in different perspectives, like that of equipment requirements for transportation, loading or unloading related problems during transportation and other perspectives during transportation, but this index is only an indication of the impacts of longer distance transportation for components from the factory to the construction sites. Thus in this study, transportation related problems during component transportation was observed in different factors and it was found as a multi-dimensional factors on components transportation stages of prefabricated elements. Therefore, transportation related problems during shipping of components are considerably greater impact in projects through time and cost dimensions, particularly for longer distance transportation. So, the improvement of standardization and technological aspects is a major solution of these problems in prefabricated construction projects.

3. The requirement of huge equipment and machinery (RII=0.79)

The requirements of heavy equipment and machines are also another challenge which is found out in the assessments of problems in prefabricated concrete components of projects in Building Technology and Construction Sector, ECWC. Through, a clear investigation of assessment of prefabricated building components in eighteen projects in Addis Ababa, the requirement of huge equipment and machinery are also another constraint in the success of concrete components construction in building projects. In this case, the study indicated that the requirement of huge equipment and machinery have also the third greater relative importance index (RII=0.79) in the assessment of problems in prefabricated concrete components in high rise buildings. So, equipment and machinery are also another problem in construction projects which in turn come in to picture as basic sources of standardization, procurement and technological factors. Thus, equipment's are also considered as the major problems in precast construction based on the finding of the study and needs to be attention for the development of prefabricated construction in the local practices.

4. Lack of Standardization and limited standards of mold (RII=0.78)

Lack of standardization and limited standards of molds in the factory is the fourth problem in the development of different standards of molds during production phase. Hence based on the study investigated, lack of standardization and limited standards of mold is categorized under the major problems that accounts about relative importance index (RII=0.78) indicating that higher impacts on prefabricated component production and construction phase of projects. Generally speaking, design and documentation related problems are the main sources of the major problems concerning lack of standardization and limited standards of molds based on the findings of the study on prefabricated building elements. Hence, standardization of various molds are also critical issues in prefabricated construction projects and it requires standardization of different molds for the improvements of these problems in Ethiopia.

5. Lack of expertise and technical knowledge (RII=0.76)

Based on the findings of this study, Lack of expertise and technical person are also other fifth major problem in prefabricated concrete components during their production and construction phases in high story building projects. As shown from figure 4.4 above, lack of experts in prefabricated concrete components have an impact of (RII=0.76) in construction progress of these elements. Moreover, this study indicates that Skill Development and human resources related problems causes' greater impact in construction and production processes of concrete parts in building projects. Hence, based on this finding, it is concluded that experts and professionals must be enhanced in order to ensure man power related factors in precast construction projects.

6. Higher Maintenance cost for equipment and molds (RII=0.75)

As mentioned earlier, higher Maintenance cost for equipment's and molds are one of the critical problems in prefabricated production and construction processes and its impact on project level is found as (RII=0.75) which rank it within the sixth category of severity of impact during the assessment of problems in eighteen projects .Generally, maintenance cost of equipment's and molds is one of the major problems which requires, special attention in prefabricated construction of building projects in Addis Ababa due to standardization and technological aspects. Therefore, according to the study found from the result, it is concluded as the maintenance costs are very critical issues for the sustain developments of factories and industries of prefabricated construction in Ethiopia.

7. The need for standard manuals, schedule of rates and Documents (RII =0.74)

According to the study conducted, the need for standard manuals, schedule of rates and Documents is identified as the seventh rank in problem assessments of precast components in buildings with degree of impact (RII=0.74).Hence, the need for standard manuals and documents is also considered to be one of the major problems faced at projects and factory. Based on this study, it is also indicated that Documentation and Design related cases are also the pin points in the category of factors to cause such problems .So, prefabricated construction companies need to develop better documentation and standard manuals to alleviate these problems.

8. Lack of Skilled Manpower (RII =0.73)

The study also showed that lack of skilled man power is one of the major problems in prefabricated concrete components in Addis Ababa building projects with severity of impact about (RII =0.73).Lack of skilled man power are those persons that include professionals and technical man powers in prefabricated concrete parts. Moreover, Skill

Development and human resources related factors cause problems in prefabricated construction of buildings. Hence, the improvement of man power is also one of the major issues in prefabricated concrete components production and construction practices in Building projects to reduce their problems both at factory level and in projects.

9. Supply and Demand related problems between factory and projects (RII =0.71)

In this study, Supply and demand related problems between factory and projects are a major problem in precast construction and fabrication. This accounts a relative importance index (RII) of about 0.71 which also have greater impact to projects during this phase. This process is occurred when the supply of the factory and demand requirements of projects don not flow smoothly during production and construction phases. And this phase is one of the major considerable factors in prefabricated components production and construction stages.

10. Inventory (Storage) cost related problems (RII =0.67)

Problem assessment in prefabricated concrete components in Addis Ababa high rise building projects also found that inventory or storage cost is the tenth higher impact on construction projects of precast components ,particularly this factor is shown merely in the local practice with severity of impact(RII=0.67). So, this problem also needs a special attention in prefabricated concrete elements in projects of building projects, particularly cost related factors.

4.2.3.2 Comparative analysis of problems in the local and international findings.

This topic deals with a comparative analysis and interpretation of prefabricated concrete components both in the local and international practices. Here, those problems with higher relative importance index greater than 0.67 and are categorized in the first ten major problems under the international and local problem assessments and analyzed in detail. Finally, common problems which have greater impact both in local and international practice was discussed and interpreted in larger context. The following table shows that the top major problems in the local and international findings of prefabricated concrete elements in high rise building projects.

Table 4.7 Top ten major problems in the international and local findings.

Ra	Problems ranked internationally		Problems ranked locally	
	Description of problems	RII	Description of problems	RII
1	High Initial Investment in facto and economies of scale	0.84	Higher Initial Investment at factory level	0.86
2	Lack of Skilled Manpower	0.81	Transportation cost and time	0.81
3	The additional burden of tax Excise &VAT for investments	0.81	The requirement of huge equipment and machinery	0.79
4	Connection and joint rela problems(Leakage)issues	0.81	Lack of Standardization and limited standards of mold	0.78
5	Joint stability Issues during Erectio	0.80	Lack of expertise and technical knowledge	0.76
6	Lack of Standardization	0.79	Higher Maintenance cost for equipment's and molds	0.75
7	Design change related issues	0.77	The need for standard manuals, Schedule of rates and Documents	0.74
8	Requirement for huge equipm &stockyards materialhandling&storage	0.76	Lack of Skilled Manpower	0.73
9	Lack of expertise and Technical knowledge	0.76	Supply and Demand related problems between factory and projects	0.71
10	Complex design issues	0.75	Inventory (Storage)cost related problems	0.67

From table 4.7, problems categorized under the first ten critical problems identified both in the international and local practice were selected, discussed, tabulated and their respective degree of impact was considered in order to focus problems that are catastrophic both international and local findings. Finally, a common problems and factors were analyzed in detail and compared in the following graph. The figure below represents the assessments of common five major problems that were identified both in the local and international studies.

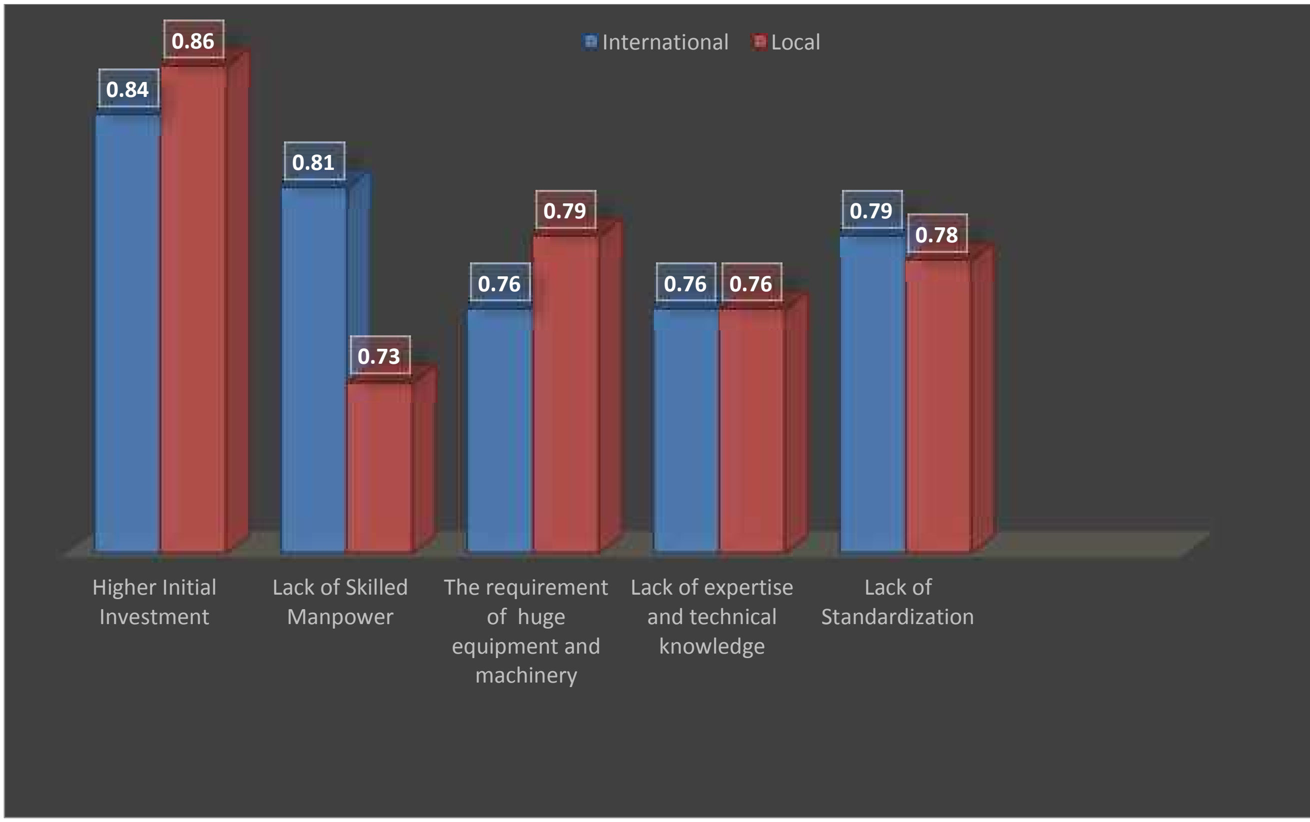

Fig 4.5. Comparison of five major problems in the local and international findings

1. Higher Initial Investment at factory level

The above figure shows that higher initial investment cost at factory level is categorized as the first catastrophic problems as indicated in the international studies (RII=0.84) and local practices (RII=0.86). Hence, from the two comparative findings of the study, we can conclude that it needs a special attention for the development of prefabricated construction in the international and local practice. However, the degree of impact in the local study indicates that it requires an immediate solution compared to other problems found in the study. In this regard, initial investment cost is the first major factor in Ethiopian precast construction compared to the international findings. Moreover, this problem is generalized under technological and scientific aspects, which needs greater attention in the local practice.

2. Lack of Skilled Manpower

The study also shows that lack of skilled man power is also other considerable problem which needs a special attention according to the international trend and in the local finding. According to the study, its degree of impact was very high (RII=0.73) that is categorized as the 8th major problems in local prefabricated construction projects and it was categorized in the 2nd major problems in the international study which was about (RII=0.81) degree of impact in prefabricated construction and production phases. Generally speaking, shortage of man power is one of the major problems that challenge the improvement and advancement of precast technology in the international and local practice. So, the study indicates that skilled man power and human resources requires a special attention for the development of prefabricated component parts in the construction of high rise building projects in Ethiopia.

3. The requirement of huge equipment and machinery

The figure also shows that the requirements of heavy equipment's and machineries are also a major problem in the local and international practice and its degree of impact is about (RII=0.79) and (RII=0.76) respectively. More generally, the study indicates that the requirements of heavy equipment's is categorized as the 3rd major problem in the local practice with (RII=0.79) where as it is categorized as the 8th major problem with degree of impact (RII=0.76) in the international trends. It is also showed that it is considerably greater impact in the local trends compared to the international impact. Here, initial cost and equipment related factors are concluded as the major factors in Ethiopian prefabricated construction and needs a particular attention for production and construction in projects.

4. Lack of expertise and technical knowledge

According to the study, lack of expertise and technical knowledge is one of the major problems faced at internationally and locally with indexes of about 0.76 which indicates that the degree of impact in both the international and local practice is the same. However, lack of expertise and technical knowledge is categorized in different ways in the local and international perspective of respondents. Hence, based on the findings of the study, it is classified as the 5th problem in the local study and is the 9th category in the international perspective. So, professionals and experts in prefabricated component production and construction fields are the mandatory requirements for successful implementation of prefabricated technology.

5. Lack of Standardization and limited standards of mold

Based on the findings of the study, it is also concluded that lack of standardization is also the major problems that have a considerable impact both in the international and local practice of prefabricated construction. In this case, limited standards of mold are a major problem particularly in the local practices. Hence, the findings show that lack of standardization is categorized as the 6th rank with degree of impact (RII=0.79) in the international perspective where as it is categorized as the 4th rank in the local perspective of respondents with degree of impact (RII=0.78).

Generally, higher initial investment cost at factory level and the requirements of heavy equipment are the most dominant problems in the local practice compared to the international findings and these factors are basically generalized as standardization, procurement and technological related problems.

4.2.3.3. Problem with least impact at projects and factory

According to the study (Table 4.6), the assessment survey also distinguishes about four problems having the least impact at projects and in the factory. The use of prefabricated concrete parts in Addis Ababa buildings faced about thirty-two major problems found during the study. Of these problems, the last four of those factors are considered to be the least impact in the use of prefabricated concrete components in building projects because of the fact that their relative importance index is below 0.40.

The following figure shows that factors with the least impact on projects of prefabricated components production and construction.

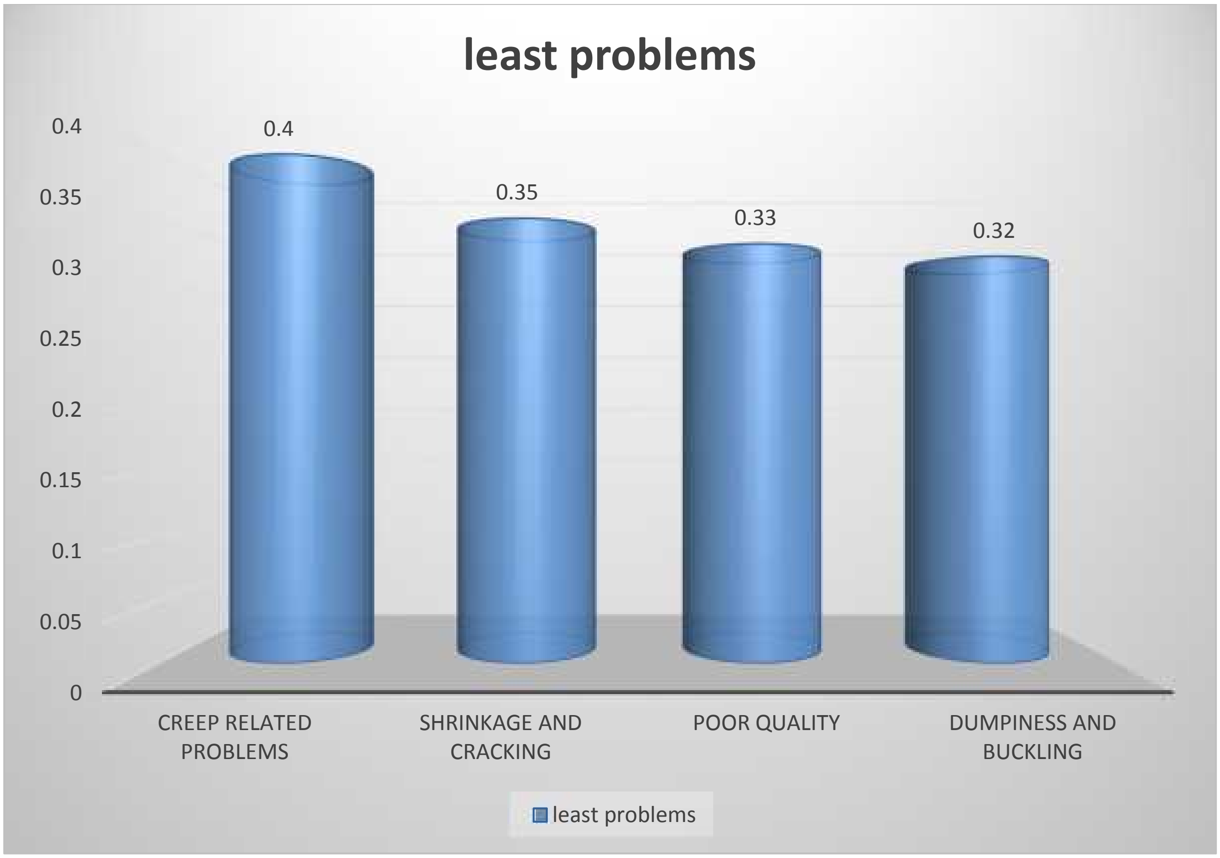

Fig 4.6 Factors with the least IIR value

1. Creep related problems

From the data analysis part of this study (table 4.6), the response of creep related problems by the respondents during the survey was mention in the 29th category of the order of the entire identified problems with (RII=0.40).This indicates that creep related problems on projects is not as such a major problem in precast construction of building projects compared to other problems.

2. Shrinkage and cracking

The study also ensured that shrinkage and cracking has not yet a greater impact after construction of prefabricated concrete components. Its relative importance index (RII=0.35) which is smaller compared to that of other factors in projects and at the factory level. So, this problem is considered to be the least problems on construction of prefabricated components in building projects.

3. Poor quality

From the study, the assessment of problems also determined the quality of prefabricated component is not the main issue in the construction of high rise building projects. The respondents assure that it is only about (RII=0.33) of severity of problems of impact in construction projects which is the least impact compared to other problems in prefabricated concrete parts.

4. Dampness and bulking related problems

Dampness is to mean wetness and non-water proofing of buildings after construction is completed. In this case, dampness and bulking related problems are found to be the least impact in problem identification of prefabricated components of high rise building projects in Addis Ababa. In this case, its impact on projects is about (RII=0.32), indicating that it is the lowest impact in prefabricated concrete component construction processes in Addis Ababa building projects. In general, creep related problems, shrinkage and cracking related factors, poor quality and dampness related problems are found to be those problems with the lowest impact on prefabricated concrete component production and construction projects and factory.

4.2.3.4 Assessment of transportation and storage cost

According to this study, problems of transportation and storage cost showed greater impacts in local practice compared to that of the international trends. Their impact of severity of problems in the international practice is lower where as their impact in the local practice is higher. The relative importance index of transportation and storage cost related problems in the local context is about (RII= 0.81) and (RII= 0.67) respectively. Unlikely to the international findings, transportation cost is ranked as the 2nd and storage cost related problems are also categorized as the 10th rank in the local practice which requires greater attention in prefabricated concrete construction and production processes. The following case evaluates a detail analysis of transportation and storage cost of prefabricated concrete components in three different projects (Goro, Ayat and Kotebe).

4.3 Analysis of transportation and storage cost (Case study)

In the study of assessment of problems in prefabricated concrete elements used in Addis Ababa building projects, transportation and storage costs were identified to be one of the major problems faced in local practice unlike to that of the international findings. These problems in the international practice are considerably least severity index on prefabricated concrete component construction projects as the study shows. Farther, the study analyzes and evaluates the transportation and storage cost problems on construction projects of prefabricated concrete components. In this case, a linear programming model with 24 decision variables, 8 constraints and the objective function was developed for single trip and solved using GAMS Software as mentioned in the introduction part of the analysis. The major objective of this analysis is to estimate the minimum transportation and storage cost between the factory and projects and to measure its impact on the factory. The analysis and result of GAMS Model is shown in Appendix2 (Appendix 2.1 and 2.2).

However, as shown in the data analysis each quantity transported is equal to the quantity stored in each projects ($X_{ij1}= X_{ij2}$).Hence, it indicates that the quantities transported and stored are the same, whereas the unit cost of transportation and storage are different depending on the scope of each projects.

The following figure illustrates the quantity of each components transported or stored in the three sites.

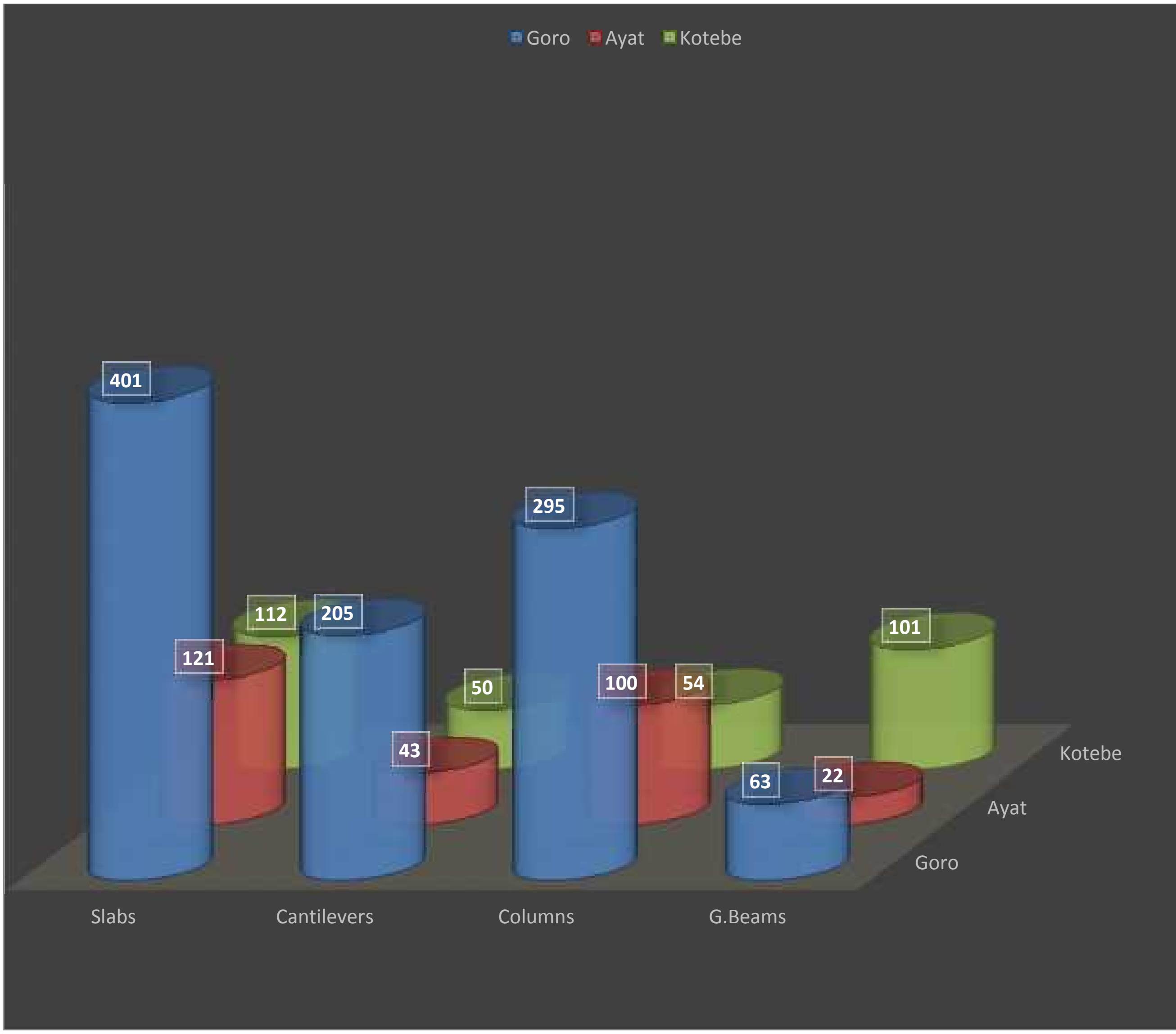

Fig4.7 The quantity of components in each projects analyzed by GAMS software.

According to the result found by the model in this study, the quantities of each components transported or stored in each site (Goro, Ayat and Kotebe) are demonstrated in the above graph. Moreover, the minimum transportation and storage cost for a single trip is found Br 54, 154.47.Beside, this result is also a foundation to calculate the total transportation and storage costs of precast elements in three projects for a number of trips.

In general, the number of trips are calculated by dividing the quantities of components obtained by the model to the number of components transported per trip according to the factories standard .But, in the company practice, quantities of slabs and columns transported per trip by the lovid with a cost of Br 11,000 are 9 and 21 respectively whereas; quantities of cantilevers and beams transported per trip by truck with a cost of Br1, 800 are 7 and 18 respectively. But, the company costs about Br76, 800 for a single transportation trip for the three projects excluding the inventory cost in projects.

Generally, the following table shows a total cost analysis of transportation and storage costs using data obtained by GAMS model throughout the construction processes.

Table4.8 Total transportation and storage cost of components by data obtained by the model.

Project	Component Type	Quantity component	No of trips	Transportation cost per unit	Storage cost per unit	Total transportation cost(Br)	Total storage cost(Br)
Goro	Slab	401	45	27.43	11.96	494,974.35	215,818.20
	Cantilev	205	30	8.78	9.13	53,997	56,149.50
	Column	295	14	37.29	5.04	154,007.70	20,815.20
	Beam	63	4	28.57	11.94	7,199.64	3,008.88
Ayat	Slab	121	14	90.91	26.03	154,001.54	44,094.82
	Cantilev	43	7	41.86	37.23	12,599.86	11,206.23
	Column	100	5	110	31.33	55,000	15,665
	Beam	22	2	81.82	50.01	3,600.08	2,200.44
Kotebe	Slab	112	13	98.21	47.10	142,993.76	68,577.60
	Cantilev	50	8	36	41.20	14,400	16,480
	Column	54	3	203.70	30.27	32,999.40	4,903.74
	Beam	101	6	17.82	8.19	10,798.92	4,963.14

The transportation and storage cost of each component in each project are obtained from the companies break down. In this case, storage and erection cost is obtained from the breakdown of each component as a percentage of 15 % of that of a unit cost of components production and construction. However, materials stored in site contain erection cost of materials; (an erection cost of 50% is deducted from the inventory cost). So, material inventory cost is calculated as 7.5% of the unit cost of materials. But, transportation cost of the factory for each component calculated as 20% of the material cost. In general, transportation cost of each component is determined by subtracting from the material cost of components in each site.

The following table shows a comparison of data obtained by the model and the current company's transportation and storage cost planned to each projects.

Table 4.9 Comparison of planned transportation and inventory cost by the company and data obtained by the model.

Project	Component Type	Cost type	Cost analyzed by the model	Actual cost of the company	Cost variation
Goro	Slab	Transportation	494,974.35	447,115.00	(47,859.35)
		Storage	215,818.20	273,670.11	57,851.91
	Cantilever	Transportation	53,997.00	73,201.04	19,204.04
		Storage	56,149.50	96,352.30	40,202.80
	Column	Transportation	154,007.70	177,231.28	23,223.58
		Storage	20,815.20	30,836.64	10,021.44
	Beam	Transportation	7,199.64	15,360.00	8,160.36
		Storage	3,008.88	8,465.62	5,456.74
Ayat	Slab	Transportation	154,001.54	134,915.00	(19,086.54)
		Storage	44,094.82	52,927.89	8,833.07
	Cantilever	Transportation	12,599.86	37,305.58	24,705.72
		Storage	11,206.23	31,186.09	19,979.86
	Column	Transportation	55,000	65,328.00	10,328.00
		Storage	15,665	21,300.56	5,635.56
	Beam	Transportation	3,600.08	15,840.00	12,239.92
		Storage	2,200.44	8,462.25	6,261.81
Kotebe	Slab	Transportation	142,993.76	124,880.00	(18,113.76)
		Storage	68,577.60	102,296.89	33,719.29
	Cantilever	Transportation	14,400	66,634.40	52,234.40
		Storage	16,480	47,890.81	31,410.81
	Column	Transportation	32,999.40	97,277.12	64,277.72
		Storage	4,903.74	33,102.30	28,198.56
	Beam	Transportation	10,798.92	22,720.00	11,921.08
		Storage	4,963.14	8,849.44	3,886.30
Total cost			**1,600,445.00**	**1,993,148.32**	**392,703.32**

The cost analysis of transportation and inventory cost between current practices of the factory and the analysis calculated by this study indicates that there is greater cost variation. According to the study, the minimum cost of quantity transported per trip is about Br76, 800 for the three projects in the current trends of the factory and the optimum cost of quantity transported or stored obtained by the model is Br 54,154.47.In this case, it is found that the cost variation of the company practice and the Model result is about Br 22,645.53 for a single trip of the three projects.

Moreover, in this finding, it is shown that the total cost of transportation and storage cost found about Br1, 600,445.00 using data obtained by the model and it is also found Br 1, 993,148.32 from the factories current practice of transportation and storage cost. Further, the total cost of variation of Br392, 703.32 (20%) is found as an extra cost of the company.

Therefore, the data analysis using GAMS optimization software in this result reduces cost of transportation and storage by about 20% compared to that of current trends of the company transportation and storage cost to projects.

In general, cost optimization models are very important to minimize the transportation and storage cost of the company during prefabricated component transportation and storage stages. This study indicates that the importance of Optimization models for scheduling of transportation and storage costs in precast transportation and storage stages. Broadly, this topic needs further studies of optimization models not only during transportation and storage stages but also in scheduling the whole investment cost of prefabricated components from production, transportation (storage) and to installation phase, particularly the importance of IBM ILOG CPLEX software as a solving tool in the analysis of these costs needs a critical issue in precast construction

CHAPTER FIVE: CONCLUSION AND RECOMMRNDATION

According to this study of using a questionnaire survey and model analysis, different problems of prefabricated concrete components are found and it is also indicated that cost related problems are identified in larger variation from this analysis.

5.1Conclusion

According to the study of prefabricated component production and construction, the initial investment cost of prefabricated production factory development is found to be one of the problematic factors in Ethiopian precast technology. In this study it is mentioned that the achievement of prefabricated construction (readymade) construction is highly influenced by initial investment cost. Similarly, transportation cost and time for longer shipment of components, the requirement of heavy equipment's and machineries, lack of standardization of molds, and manpower related factors are also other major problems following that of initial investment cost at factory level.

Based on the study, very catastrophic problems during the production, erection and whole construction phases are also identified both in the international and local perspectives of the study. In this case, initial investment cost is still needs a special attention not only in local practice but also in international practice. Hence, in this study major problems that are found to be greater impact in prefabricated production and construction phase both in the local and international trends that requires a special attention are that of initial cost, lack of skilled manpower, the requirements of heavy equipment's, lack of experts and limited standards of molds etc.

Conversely, problems that are identified with lower impact is also another important topic in this study, which is concluded creep related problems, cracks or shrinkage and quality related factors are relatively found as the least impact in projects or factory. So, these factors in contradict have the relative importance index of less than 0.40, this shows that its impact in prefabricated concrete elements production and construction phase are relatively smaller compared to other factors.

On the other hand, the assessment of cost related factors in Building Technology and Construction, Sector and its projects are also indicated that almost 20% of the transportation and storage cost is an extra cost lost in the company due to less emphasis given to planning issues and less emphasis given to optimization models.

Generally, from the data analysis and interpretation part of this study, it is concluded that the majority of problems in prefabricated concrete components are because of their development and requirement of standards, procurements of technological aspects and cost related problems which are mostly before construction completion of projects.

5.2 Recommendations

Based on the study, results showed that the factors or problems assessed are more related to technological impacts and requiring of heavy machines. Hence, based on the findings obtained it should be recommended that:

- Mostly, governmental support for the development of the factory is a viable solution to ensure initial investment cost related factors in the country and or attraction of foreign investors are also other issues for successful development of prefabricated factories in Ethiopia.
- Besides, the company should aggressively ensure the involvement of promotion and announcement of the products. It also make a relationship of governmental and non-governmental companies in training strategy and in preparing documents, manuals and standards that are important in the production and design stages of these elements.
- The company also ensures market research, shares new technologies and techniques with other foreign companies and they also make a linkage with universities (UIL).The competency and encouragement of the company should be enhanced and the maintenance and repairing of equipment's are also ensured.
- Similarly, the needs of important professionals and skilled man power should be trained in the company in order to attain the goal of prefabricated concrete components in Ethiopian construction industry.
- The company should also exercise cost optimization models to minimize the transportation and storage cost.
- In this case, optimization models are not only used for storage and transportation optimization, but they are also critical for solving the whole investment cost of the factory

beginning from the production, transportation, inventory and to the final erection cost analysis stage of prefabricated construction.

- Generally, the company should develop cost planning techniques during transportation and storage stages to minimize their transportation and storage cost in the factory in particular and cost planning techniques of cost analysis from production to construction phases in general.

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Appendix

Appendix 1: Questionnaire Survey, Measurements and formulas

Addis Ababa Science& Technology University

College of Architecture & Civil Engineering

"Assessment of problems in prefabricated concrete elements used in Addis Ababa building projects. The case of Building Technology and Construction Sector, ECWC".

Thesis Submitted to School of Graduate Studies in Partial fulfillment of the requirements for the Degree of Master of Science in Civil Engineering (Construction Technology and Management)

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SECTION One: Questionnaire survey

This research study is designed to fulfill an academic requirement for post graduate program in Civil Engineering with a specialization of Construction Technology and Management in Addis Ababa Science and Technology University. This thesis is conducted for the identification and assessment of major problems of precast elements in the construction of high rise buildings. Here, the questionnaire deals particularly to site engineers, Supervisors, technical persons and machine operators who engaged in prefabricated concrete construction for selected building projects.

In general, I will assure you that the research data will only be used solely for the academic requirement and will be treated with strict confidentiality. Your open and prompt response is highly appreciated.

Objective of the survey

The basic aim of the survey is that to gather reliable information in order to achieve the following research objectives:

- To identify and review the critical problems of prefabricated concrete building components, especially in the construction of high rise building projects in Addis Ababa.
- To initiate cost scheduling techniques of prefabricated concrete elements in the construction of building projects as well as in production factories.
- To minimize storage and transportation cost of prefabricated concrete building parts in construction projects in Ethiopia.
- To provide an in depth roots of prefabricated concrete components in the use and application of high rise building projects in Ethiopia.

RESEARCHER'S INFORMATION

Name: Gebeyaw Taddele

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Please tick (√) or write short answer to provide your answer.

Part I: Personnel information

1. Project Name: ___________________________

Client: ______________________________

Contractor: ___________________________

2. Story of the Building: ______________________

G+0 ☐ G+1 ☐ G+2 ☐ G+3 ☐

G+4 ☐ G+5 ☐ G+6 ☐ G+7 ☐

Write the story if it is above G+7 ☐

3. Sex: Male ☐ Female ☐

4. Responsibility in the company:

Site Engineer ☐ Supervisor ☐

Project Manager ☐ Erector ☐

Office Engineer ☐ Machine operator ☐

Forman ☐

5. Your service in the company

1-5 years ☐ 11-15 years ☐

6-10years ☐ Greater than15 years ☐

Part II: Assessment of Major Problems of prefabricated concrete elements used in Addis Ababa building projects.

Here problems should be generalized as:

1. Standardization, Procurement, and Technological aspects

2. Documentation and Design aspects

3. Skill Development and human resources

4. End-user perspective (acceptability and social dimensioning).

Please choose the degree of impact of each problems listed below that you face in your project or industry.

Note: The above numbers to indicate their generalization on the category column are filled by the researcher only.

Table 1.a.List of problems

No	Problem Descriptions at projects	Possible Causes	Degree of impact at project level				
			Very hig	High	Interme iate	Low	Very low
1	Higher Initial Investment at factory level						
2	Lack of Skilled Manpower						
3	Transportation cost and time						
4	The requirement of huge equipment and machinery						
5	Lack of expertise and technical knowledge						
6	Complex design issues						
7	Design change related problems						

8	Installation and erection related problems during construction						
9	Higher Maintenance cost for equipment's and molds						
10	Scheduling-LeadTime&delivery cases						
11	Connection and joint related problems(Leakage)						
12	Loading and un loading related problems during transportation						
13	Handling (component size and weight) related problems for high rise building projects.						
14	Inventory (Storage) cost related problems						
15	Shrinkage and cracking related problems						
16	Aesthetic related problems for clients						
17	Frequent occurrence of accidents on workers due to i size and weight in high rise building projects						
18	The need for standard manuals, schedule of rates and Documents.						
19	Lack of Standardization and limited standards of mo						
20	The requirement of greater working space in Urban areas						
21	Low resistance to earth quakes and seismic load						
22	Poor quality compared to conventional construction						
23	Creep related problems after construction						
24	Material consumption related problems						
25	Dumpiness and buckling related problems after construction						
26	Boring related problems on workers as compared to conventional construction						
27	Durability related problems for clients						
28	Supply and Demand related problems between factor and projects						
29	Misalignment and non-overlapping problems at projects						
30	Construction Difficulty during rainy season compare to conventional construction						
31	The requirement of extra cost of admixture						
32	The difficulty of de-molding and striping during curing						

SECTION TWO: Case study

Assessment of the case of storage and transportation cost related factors during transportation and storage of components in selected projects. Measurements and Observations of common prefabricated elements taken from the factory and sites for identification of productivity factors.

I. Measurements

The following tables show that the measurements of each components in the factory and in the three sites.

Table 1.b Measurements taken from the three projects.

Components	Parameters					
	Specification	Length(m)	Width(m)	Height(m)	Weight(kg)	Mix Design Concrete volume (m^3)
Slabs	**Isolated**	**4.2**	**4.2**	**.22**	**3200**	**1.28**
	With ceiling	4.2	4.2	.22	4425	1.32
Cantilevers	**S34-CB**	**4.5**	**1.28**	**.22**	**1425**	**0.57**
	S34-CL	4.34	1.28	.32	1350	0.54
	S34-CM	4.12	1.28	.32	1250	0.5
	S34-CR	4.2	1.2	.22	1175	0.48
Columns	Initial Columns	0.3	0.3	3.63	1050	0.42
	1-Story columns	0.3	0.3	3.5	1675	0.55
	2-Story Columns	**0.34**	**0.34**	**5.79**	**2500**	**0.67**
	3-Story columns	0.34	0.34	8.69	3000	1
Girder beams	**Edge Girder**	**4.2**	**1.2**	**0.22**	**2888**	**0.115**

	G34-1					
	Edge Girder G34-2	4.2	1.2	0.17	510	0.204
	Edge Girder G34-4	3.90	1.2	0.17	450	0.162
Shear walls		3.78	2.62	0.15	6000	1.5
Footings	F1	1.2	1.2	0.8	1475	0.69
	F2	1.6	1.6	0.8	2175	.87
	F3	2	2	0.8	2950	1.18
Stairs	Stair case flight	2.9	1.16	0.8	1788	0.715
	Stair case Landing	4	1.45	0.8	200	0.8

II. Modeling and Symbolizing of quantities taken from the site and a factory using the company's transportation and storage cost standard.

Table 1.c. Unit cost of transportation and storage

Project Sites	Component type	Cost Item	Cost (Birr/unit)	Symbols(Quantities)
Gorro-ICT Incubation Center	Slabs	Transportation	27.43	X_{111}
		Storage	11.96	X_{112}
	Cantilevers	Transportation	8.78	X_{121}
		Storage	9.13	X_{122}
	Columns	Transportation	37.29	X_{131}
		Storage	5.04	X_{132}
	Girder beams	Transportation	28.57	X_{141}
		Storage	11.94	X_{142}
Ayat-Melese Zenawi Leader ship Academy	Slabs	Transportation	90.91	X_{211}
		Storage	26.03	X_{212}
	Cantilevers	Transportation	41.86	X_{221}
		Storage	37.23	X_{222}
	Columns	Transportation	110	X_{231}
		Storage	31.33	X_{232}
	Girder beams	Transportation	81.82	X_{241}

		Storage	50.01	X_{242}
Kotebe-Metropolitan University Administration office	Slabs	Transportation	98.21	X_{311}
		Storage	47.1	X_{312}
	Cantilevers	Transportation	36	X_{321}
		Storage	41.2	X_{322}
	Columns	Transportation	203.7	X_{331}
		Storage	30.27	X_{332}
	Girder beams	Transportation	17.82	X_{341}
		Storage	8.19	X_{342}

Table1.d The quantity of components supplied by the factory and overhead cost incurred for projects.

Component type	Total supply of components for 3-projects (Pcs)	Average Production cost(Birr)	Total inventory cost (Birr)
Slab	634	66,103.6	13,220.72
Cantilever	298	27,666.65	5,533.33
Column	449	31,267.45	6,253.49
Girder Beam	186	13,397.5	2,679.50

Formulation of optimization model from the above tables is:

Objective function

MinZ= 27.43 X_{111}+11.96 X_{112}+8.78 X_{121}+9.13 X_{122}+37.29 X_{131}+5.04 X_{132}+28.57 X_{141}+11.94 X_{142}+90.91 X_{211}+26.03 X_{212}+41.86 X_{221}+37.23 X_{222}+110 X_{231}+ 31.33X_{232}+81.82 X_{241}+ 50.01X_{242}+98.21 X_{311}+47.1 X_{312}+36X_{321}+41.2 X_{322}+203.7 X_{331}+30.27 X_{332}+ 17.82X_{341}+8.19 $X_{34.}$

Constraint Equations.

Quantity of Components transported:

Slabs: $X_{111}+ X_{211}+ X_{311} =634$

Cantilevers: $X_{121} +X_{221}+ X_{321}=298$

Columns: $X_{131}+ X_{231+} X_{331}=449$

Girder Beams: $X_{141}+ X_{241}+ X_{341}=186$

Quantity of Components stored:

Slabs: $X_{112}+ X_{212}+ X_{312} =634$

Cantilevers: $X_{122} +X_{222}+ X_{322} =298$

Columns: $X_{132}+ X_{232+} X_{332}=449$

Girder Beams: $X_{142}+ X_{242}+ X_{342}=186$**.** Where,

$\mathbf{X_{111}}$-Quantity of slabs transported to Gorro
$\mathbf{X_{112}}$-Quantity of slabs stored in Gorro
$\mathbf{X_{121}}$-Quantity of Cantilevers transported to Gorro
$\mathbf{X_{122}}$-Quantity of Cantilevers Stored in Gorro
$\mathbf{X_{131}}$-Quantity of columns transported to Gorro
$\mathbf{X_{132}}$-Quantity of columns stored in Gorro
$\mathbf{X_{141}}$-Quantity of Girder beams transported to Gorro
$\mathbf{X_{142}}$-Quantity of Girder beams stored in Gorro
$\mathbf{X_{211}}$-Quantity of slabs transported to Ayat
$\mathbf{X_{212}}$-Quantity of slabs stored in Ayat
$\mathbf{X_{221}}$-Quantity of Cantilevers transported to Ayat
$\mathbf{X_{222}}$-Quantity of Cantilevers Stored in Ayat
$\mathbf{X_{231}}$-Quantity of columns transported to Ayat
$\mathbf{X_{232}}$-Quantity of columns stored in Ayat
$\mathbf{X_{241}}$-Quantity of Girder beams transported to Ayat
$\mathbf{X_{242}}$-Quantity of Girder beams stored in Ayat
$\mathbf{X_{311}}$-Quantity of slabs transported to Kotebe
$\mathbf{X_{312}}$-Quantity of slabs stored in Kotebe
$\mathbf{X_{321}}$-Quantity of Cantilevers transported to Kotebe
$\mathbf{X_{322}}$-Quantity of Cantilevers Stored in Kotebe
$\mathbf{X_{331}}$-Quantity of columns transported to Kotebe
$\mathbf{X_{332}}$-Quantity of columns stored in Kotebe
$\mathbf{X_{341}}$-Quantity of Girder beams transported to Kotebe
$\mathbf{X_{342}}$-Quantity of Girder beams stored in Kotebe

Appendix 2: Analysis and Result of GAMS Model

2.1 GAMS ANALYSIS

$ontext

Objective function: minimize Z= 27.43 X111+11.96 X112+8.78 X121+9.13 X122+37.29 X131+5.04 X132+28.57 X141+11.94 X142+90.91 X211+26.03 X212+41.86 X221+37.23 X222+110 X231+ 31.33X232+81.82 X241+ 50.01X242+98.21 X311+47.1 X312+36X321

+41.2 X322+203.7 X331+30.27 X332+ 17.82X341+8.19 X342

Constraint Equation:

Slabs: X111+ X211+ X311 =634

Cantilevers: X121 +X221+ X321 =298

Columns: X131+ X231+ X331 =449

Girder Beams: X141+ X241+ X341 =186

Slabs: X112+ X212+ X312 =634

Cantilevers: X122 +X222+ X322 =298

Columns: X132+ X232+ X332 =449

Girder Beams: X142+ X242+ X342 =186

$offtext

VARIABLES Z;

*z is the objective function

POSITIVE VARIABLES X111,X112,X121,X122,X131,X132,X141,X142,X211,X212,

X221,X222,X231,X232,X241,X242,X311,X312,X321,X322,X331,X332,X341,X342;

*X111=Quantity of slabs transported to Gorro

*X112=Quantity of slabs stored in Gorro

*X121=Quantity of Cantilevers transported to Gorro

*X122=Quantity of Cantilevers Stored in Gorro

*X131=Quantity of columns transported to Gorro

*X132=Quantity of columns stored in Gorro

*X141=Quantity of Girder beams transported to Gorro

*X142=Quantity of Girder beams stored in Gorro

*X211=Quantity of slabs transported to Ayat

*X212=Quantity of slabs stored in Ayat

*X221=Quantity of Cantilevers transported to Ayat

*X222=Quantity of Cantilevers Stored in Ayat

*X231=Quantity of columns transported to Ayat

*X232=Quantity of columns stored in Ayat

*X241=Quantity of Girder beams transported to Ayat

*X242=Quantity of Girder beams stored in Ayat

*X311=Quantity of slabs transported to Kotebe

*X312=Quantity of slabs stored in Kotebe

*X321=Quantity of Cantilevers transported to Kotebe

*X322=Quantity of Cantilevers Stored in Kotebe

*X331=Quantity of columns transported to Kotebe

*X332=Quantity of columns stored in Kotebe

*X341=Quantity of Girder beams transported to Kotebe

*X342=Quantity of Girder beams stored in Kotebe

EQUATIONS   OBJ, traslab,strslab,tracant,strcant,tracol,strcol,trabem,

strbem ;

$ontext

obj   = objective function

traslab =transporting slabs

strslab = storing slabs

tracant = transporting cantilevers

strcant = storing cantilevers

tracol =transporting columns

strcol = storing columns

trabem = transporting Girder beams

strbem = storing Girder beams

$offtext

OBJ..   Z =E= 27.43* X111+11.96 *X112+8.78* X121+9.13* X122+37.29* X131

+5.04 *X132+28.57 *X141+11.94 *X142+90.91* X211+26.03* X212+41.86* X221+37.23 *X222+110* X231+ 31.33*X232+81.82 *X241+50.01*X242+98.21 *X311+47.1 *X312+36*X321+41.2* X322+203.7* X331+30.27* X332+17.82*X341+8.19 *X342;

traslab..   X111+ X211+ X311 =E= 634;

strslab..   X112+ X212+ X312 =E= 634;

```
tracant..      X121 +X221+ X321  =E= 298;

strcant..      X122 +X222+ X322  =E= 298;

tracol..       X131+ X231+ X331  =E= 449;

strcol..       X132+ X232+ X332  =E= 449;

trabem..       X141+ X241+ X341  =E= 186;

strbem ..      X142+ X242+ X342  =E= 186;

MODEL prefabricated /ALL/;

SOLVE prefabricated USING LP MINIMIZING Z;
```

2.2 GAMS RESULTS

```
   S O L V E     S U M M A R Y

    MODEL   prefabricated      OBJECTIVE Z

    TYPE    LP                DIRECTION MINIMIZE

    SOLVER CPLEX              FROM LINE 92

**** SOLVER STATUS     1 Normal Completion

**** MODEL STATUS      1 Optimal

**** OBJECTIVE VALUE           54154.4700

 RESOURCE USAGE, LIMIT          0.006      1000.000

 ITERATION COUNT, LIMIT         0    2000000000

 IBM ILOG CPLEX   BETA 6Nov10 23.6.0 WIN 21006.21007 VS8 x86/MS Windows

Cplex 12.2.0.1, GAMS Link 34

 LP status(1): optimal
```

Optimal solution found.

Objective: 54154.470000

	LOWER	LEVEL	UPPER	MARGINAL
---- EQU OBJ	.	.	.	1.000
---- EQU traslab	634.000	634.000	634.000	27.430
---- EQU strslab	634.000	634.000	634.000	11.960
---- EQU tracant	298.000	298.000	298.000	8.780
---- EQU strcant	298.000	298.000	298.000	9.130
---- EQU tracol	449.000	449.000	449.000	37.290
---- EQU strcol	449.000	449.000	449.000	5.040
---- EQU trabem	186.000	186.000	186.000	17.820
---- EQU strbem	186.000	186.000	186.000	8.190

	LOWER	LEVEL	UPPER	MARGINAL
---- VAR Z	-INF	54154.470	+INF	.
---- VAR X111	.	401.000	+INF	.
---- VAR X112	.	401.000	+INF	.
---- VAR X121	.	205.000	+INF	.
---- VAR X122	.	205.00	+INF	.
---- VAR X131	.	295000	+INF	.
---- VAR X132	.	295.000	+INF	.

---- VAR X141	.	63 .000	+INF	.
---- VAR X142	.	63.000	+INF	.
---- VAR X211	.	121.070	+INF	.
---- VAR X212	.	121.070	+INF	.
---- VAR X221	.	43.080	+INF	.
---- VAR X222	.	43.080	+INF	.
---- VAR X231	.	99.900	+INF	.
---- VAR X232	.	100.710	+INF	.
---- VAR X241	.	21.820	+INF	.
---- VAR X242	.	22.740	+INF	.
---- VAR X311	.	111.800	+INF	.
---- VAR X312	.	112.102	+INF	.
---- VAR X321	.	49.720	+INF	.
---- VAR X322	.	50.200	+INF	.
---- VAR X331	.	53.610	+INF	.
---- VAR X332	.	54.030	+INF	.
---- VAR X341	.	100.980	+INF	.
---- VAR X342	.	100.890	+INF	.

Appendix3.Projects and their Summary Break downs

3.1Ayat Project

PREFABRICATED BUILDING PARTS PRODUCTION ENTERPRISE

AYAT MELESE ZENAWI LEADER SHIP ACADAMY

CONSTRUCTION OF SKELETON IN PRE-FAB ELEMENTS

SUMMARY OF COSTS

No	Description	Unit	Qty	price(including mater. & transp.) in birr		price(with out mater. & transp.) in birr		Difference in birr
				Unit price	Total	unit price	Total	
1	Normal Slab type S-34-N (420*420)	Pcs	121	24,049.50	2,909,989.50	21,262.00	2,572,702.00	337,287.50
2	cantilever slab(420*120)	pcs	43	14,137.72	607,921.96	10,806.00	464,658.00	143,263.96
2	Cantilever slab S-34-CL	Pcs	18	7,596.23	136,732.14	4,264.51	76,761.18	59,970.96
3	Cantilever slab S-34-CM	Pcs	28	7,937.13	222,239.64	4,274.10	119,674.80	102,564.84
4	Cantilever slab S-34-CR	Pcs	14	8,236.83	115,315.62	4,264.51	59,703.14	55,612.48
	Edge Girder/17*22*420/	pcs	22	9,227.00	202,994.00	7,427.00	163,394.00	39,600.00
	Stair girder(G4)	pcs	6	5,821.00	34,926.00	5,321.00	31,926.00	3,000.00
5	Edge girder G-30-1	Pcs	15	1,811.12	27,166.84	1,960.11	29,401.65	(2,234.81)
6	Edge girder G-30-2	Pcs	44	2,385.31	104,953.72	2,004.06	88,178.64	16,775.08
7	Edge girder G-30-4	Pcs	5	2,225.70	11,128.48	2,099.50	10,497.50	630.98
8	Initial Column C-30-1W(l=7m)	Pcs	58	12,362.15	717,004.70	9,142.60	530,270.80	186,733.90
9	Initial Column (1400 cm)	pcs	42	13,792.55	579,287.10	10,573.00	444,066.00	135,221.10
10	Column C-30-1W-350cm(1-story)	Pcs	58	11,532.96	668,911.68	10,573.00	613,234.00	55,677.68
	2-Story columnn(1,580cm)	pcs	42	30,279.20	1,271,726.40	21,146.00	888,132.00	383,594.40
11	Column C-30-2W-580cm(2-story)	Pcs	58	30,279.20	1,756,193.60	21,146.00	1,226,468.00	529,725.60
11	Shearwall 378x262x15	Pcs	24	10,112.33	242,695.97	4,495.68	107,896.32	134,799.65
12	Staircase flight(120*320)	Pcs	6	9,625.96	57,755.76	8,539.90	51,239.40	6,516.36
13	Staircase landing(120*390)	Pcs	3	18,707.06	56,121.18	16,417.00	49,251.00	6,870.18
14	Footing pad F1(120x120x80cm)	Pcs	16	9,381.24	150,099.84	7,007.30	112,116.80	37,983.04
15	Footing pad F2(160x160x80cm)	Pcs	100	14,636.60	1,463,660.00	8,539.30	853,930.00	609,730.00
TOTAL			723		11,336,824.12		8,493,501.23	2,843,322.89

Summary of cost Breakdown of Ayat –MeleseZenawi Leader Ship Academy Project.

3.2Goro Project ICT Incubation Center

PREFABRICATED BUILDING PARTS PRODUCTION ENTERPRISE								
INFORMATION AND COMMUNICATION INCUBATION CENTER								
CONSTRUCTION OF SKELETON IN PRE-FAB ELEMENTS (B+G+7)								
SUMMARY OF COSTS								
				price(including mater. & transp.) in birr		price(with out mater. & transp.) in birr		Difference
No	Description	Unit	Qty	Unit price	Total	unit price	Total	in birr
1	Normal Slab type S-34-N (420*42	Pcs	401	35,157.50	14,098,157.50	32,370.00	12,980,370.00	1,117,787.50
2	cantilever slab(420*120)	pcs	205	15,971.72	3,274,202.60	12,640.00	2,591,200.00	683,002.60
2	Cantilever slab S-34-CL	Pcs	12	7,596.23	91,154.76	4,264.51	51,174.12	39,980.64
3	Cantilever slab S-34-CM	Pcs	36	7,937.13	285,736.68	4,274.10	153,867.60	131,869.08
4	Cantilever slab S-34-CR	Pcs	12	8,236.83	98,841.96	4,264.51	51,174.12	47,667.84
	Edge Girder/17*22*420/	pcs	63	6,876.00	433,188.00	5,076.00	319,788.00	113,400.00
	Stair girder(64)	pcs	4	5,821.00	23,284.00	5,321.00	21,284.00	2,000.00
5	Edge girder G-30-1	Pcs	5	1,811.12	9,055.61	1,960.11	9,800.55	(744.94)
6	Edge girder G-30-2	Pcs	14	2,385.31	33,394.37	2,004.06	28,056.84	5,337.53
7	Edge girder G-30-4	Pcs	8	2,225.70	17,805.57	2,099.50	16,796.00	1,009.57
8	Initial Column C-30-1W(l=7m)	Pcs	75	11,530.55	864,791.25	8,311.00	623,325.00	241,466.25
10	Column C-30-1W-350cm(1-story	Pcs	295	11,532.96	3,402,223.20	10,031.00	2,959,145.00	443,078.20
11	Column C-30-2W-580cm(2-story	Pcs	36	30,279.20	1,090,051.20	21,146.00	761,256.00	328,795.20
11	Normal shear wall386x338x25	Pcs	84	36,286.65	3,048,078.60	30,670.00	2,576,280.00	471,798.60
12	Staircase flight(290*125cm)	Pcs	18	14,101.06	253,819.08	13,015.00	234,270.00	19,549.08
	Stair case flight Girder(175*125	pcs	9	7,596.06	68,364.54	6,510.00	58,590.00	9,774.54
13	Staircase landing(165*135cm)	Pcs	18	27,011.06	486,199.08	24,721.00	444,978.00	41,221.08
14	Footing pad F1(120x120x80cm)	Pcs	10	9,381.24	93,812.40	7,007.30	70,073.00	23,739.40
15	Footing pad F3(160x160x80cm)	Pcs	48	14,636.60	702,556.80	8,529.30	409,886.40	292,670.40
TOTAL			1353		28,374,717.20		24,361,314.63	4,013,402.57

Summary of Cost Breakdown of Goro ICT Incubation Center Project.

3.3 Kotebe Metropolitan University Administration office

PREFABRICATED BUILDING PARTS PRODUCTION ENTERPRISE								
KOTEBE METROPOLITIA UNIVERSITY ADMISTRATION OFFICE								
CONSTRUCTION OF SKELETON IN PRE-FAB ELEMENTS								
SUMMARY OF COSTS								
				price(including		price(with out		Difference
No	Description	Unit	Qty	Unit price	Total	unit price	Total	in birr
1	Normal Slab type S-34-N (420*4	Pcs	112	38,395.30	4,300,273.60	35,607.80	3,988,073.60	312,200.00
2	cantilever slab(S-34-CB)	pcs	3	17,235.72	51,707.16	13,904.00	41,712.00	9,995.16
2	Cantilever slab S-34-CL	Pcs	13	17,235.72	224,064.36	13,904.00	180,752.00	43,312.36
3	Cantilever slab S-34-CM	Pcs	21	17,235.72	361,950.12	13,904.00	291,984.00	69,966.12
4	Cantilever slab S-34-CR	Pcs	13	17,235.72	224,064.36	13,904.00	180,752.00	43,312.36
	Edge Girder/17*22*420/	pcs	20	9,227.00	184,540.00	7,427.00	148,540.00	36,000.00
	Stair girder(G4)	pcs	8	5,821.00	46,568.00	5,321.00	42,568.00	4,000.00
5	Edge girder G-34-1	Pcs	20	7,383.60	147,672.00	5,583.60	111,672.00	36,000.00
6	Edge girder G-34-2	Pcs	77	7,383.60	568,537.20	5,583.60	429,937.20	138,600.00
7	Edge girder G-34-4	Pcs	4	7,383.60	29,534.40	5,583.60	22,334.40	7,200.00
8	Initial Column C-34-1W(l=7m)	Pcs	54	12,361.65	667,529.10	9,142.10	493,673.40	173,855.70
10	Column C-34-1W(1-story)	Pcs	36	10,102.06	363,674.16	9,142.10	329,115.60	34,558.56
	2-Story columnn-C-34 -2w (579cn	pcs	54	20,167.30	1,089,034.20	11,034.10	595,841.40	493,192.80
11	Shearwall 378x262x15	Pcs	24	10,112.33	242,695.97	4,495.68	107,896.32	134,799.65
12	Staircase flight(120*320)	Pcs	8	9,625.96	77,007.68	8,539.90	68,319.20	8,688.48
13	Staircase landing(120*390)	Pcs	4	18,707.06	74,828.24	16,417.00	65,668.00	9.00
14	Footing pad F2(160x160x80cm)	Pcs	36	16,809.24	605,132.64	14,435.30	519,670.80	85,461.84
15	Footing pad F3(200x200x80cm)	Pcs	2	20,130.10	40,260.20	17,756.20	35,512.40	4,747.80
TOTAL			509		9,299,073.39		7,654,022.32	1,635,899.83

Summary of cost breakdown Kotebe Metropolitan University Administration Office